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Analytical and Experimental Studies on Steel and Composite Mono Leaf Spring

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Abstract: *This paper describes static and fatigue analysis of steel and composite leaf spring made of E-glass fiber/epoxy. The design parameters are considered to be same for both springs. Composite mono leaf spring was fabricated utilizing hand lay- up technique with distinguishing different fiber orientation such as, $[0/45/0/45]_s$. The outcome of the experiment was validated by FEA. At full load, the stress in the composite leaf spring observed was 53.06 % less than a steel leaf spring with higher stiffness. The conventional steel leaf spring weighs about 10.5 kg, whereas the spring made with E-glass /epoxy weighs only 2.67 kg. Thus, weight reduction of 74.49% was accomplished. The fatigue life of composite leaf spring (100000 cycles) spring was more than that of conventional steel leaf spring. 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. Better agreement between experimental result and FEA is observed.*

Key words**:** *Steel leaf spring, E-glass fiber/epoxy, Static analysis, Fatigue analysis, Finite element analysis.*

I. Introduction

Increasing competition and innovations in automobile sector tends to modify the existing products or replacing old products by new and advanced material products. A suspension system of vehicle is also an area where these innovations are carried out regularly. The leaf spring used in vehicle should absorb vertical vibration due to irregularities by means of deviation in the spring deflection, so that potential energy is stored in the spring as strain energy and released slowly [1-4]. The composite material is having distinctive characteristic such as, high strength to weight ratio, superior fatigue strength, excellent corrosion resistance beside this have higher natural frequency thus , this makes composite materials are excellent for leaf spring. Main factor that contribute fatigue failure that include number of cycles experienced, range of stress and mean stress experienced in each load cycle. When leaf spring deflects, rubbing between upper and lower side is occurred and this produce some damping, nevertheless, this induces squeaking sound and this in turn develop interleaf friction between leaves will also cause fretting corrosion which reduce fatigue strength of leaf spring. So, the leaf springs are more affected due to fatigue loads, as they are a part of the unsprung mass of the automobile. Due to the cyclic load on a suspension system of vehicle it can be failed. Thus, fatigue study and life prediction on the suspension system is crucial in order to verify the safety of suspension system during its operation. The fatigue life in steel and glass fiber reinforced plastic was predicted using damage model [5].Three cumulative damage models are examined for the case of cyclic loading of AISI 6150 steel, S2 fibre/epoxy and E glass fibre/epoxy composites. A prediction of fatigue life of steel and composite leaf spring was presented based on applied stress level. [6]. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle are taken and are verified by design calculations. Finite element approach for design and stress-deflection analysis of a multi leaf spring using CAE tools. and indicates that when the leaf spring is fully loaded, a variation of 0.632 % in deflection is observed between the experimental and FEA result[7]. A static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fibre reinforced polymer were described using life data analysis[8]. In the present work, four-leaf steel spring used in light commercial vehicle is replaced with a composite mono leaf spring made of glass/epoxy composites. The dimensions for both steel leaf spring and composite leaf springs are considered to be the same.

II. Objectives

- Compare load carrying capacity, stiffness and weight savings of composite leaf spring with steel leaf spring
- Fabrication of E-glass/epoxy based composite mono leaf spring with $[0/45/0/45]_s$.
- To validate performance of steel and composite mono leaf spring for static analysis.
- To determine Fatigue life of composite leaf spring.

III. Methodlogy

3.1 Specification of conventional leaf spring

All leaf spring made up of various fine grade alloy steel. The test steel used for experimental work is made of 55SI2Mn90. The composition of material is 0.55C%,1.74 Si%,0.87 Mn%,0.1 Cr%,0.02 Mo%,0.05 P%, 0.05 S%.

Table 1. Specification of Existing steel leaf spring

Sr.no	Parameters	Value
	total length (eye to eye)	860 mm
	Arc height of axle seat (camber)	90 mm
	spring rate	23.1 N/mm
	number of full-length leaves	01
	number of graduated leaves	03
	width of leaves	60mm
	thickness of each leaves	08 mm
	full bump loading	2084N
	spring weight	10.5 Kg;
	Young's modulus	$2.1x10^5$MPa
	Available space for spring width	40-45 mm

3.2 Manufacturing of composite mono leaf spring

It is well known that the stored elastic strain energy in a leaf spring varies directly with the square of maximum allowable stress and inversely with the modulus of elasticity both in longitudinal and transverse directions according to equation (1)

$$S=\frac{1\sigma^2}{2\rho E} \qquad \text{….. (1)}$$

Strain energy stored by various composite material is illustrate in table1. As E-glass fiber has good characteristic in direction of fiber and also have good storing strain energy. Composite materials can be tailored to meet the particular requirements of stiffness and strength with varying lay-up and fiber orientations.

Table 2: Strain energy stored by various composite material

Sr.No.	Material	Strain Energy (k J/kg)
1	Steel	0.325
2	E-glass/Epoxy	4.5814
3	C-glass/Epoxy	18.76
4	S-2 glass/Epoxy	32.77

Table.3 : Mechanical properties of E-glass/Epoxy

Sr.No.	Properties	Value
1	Tensile modulus along X- direction (Ex), Mpa	34000
2	Tensile modulus along Y- direction (Ey), Mpa	6530
3	Tensile modulus along Z- direction (Ez), Mpa	6530
4	Shear modulus along XY-direction (Gxy),Mpa	2433
5	Shear modulus along YZ-direction (Gyz), Mpa	1698
6	Shear modulus along ZX-direction (Gzx), Mpa	2433
7	Poisson ratio along XY-direction (Nuxy)	0.217
8	Poisson ratio along YZ-direction (Nuyz)	0.366
9	Poisson ratio along ZX-direction (Nuzx)	0.217
10	Mass density of material (ρ), kg/mm^3	$2.6x10^{-6}$
11	Tensile strength of the material, MPa	900
12	Compressive strength of the material,MPa	610
13	Flexural strength of the material, MPa	1200
14	Flexural modulus of the material, MPa	4000

3.3 Fabrication of mono composite leaf spring using hand lay-up technique

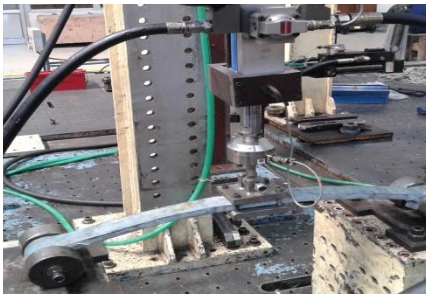
Hand lay-up process is most appropriate because this does not require any skilled labor or rather particular kind of tooling and equipment. Before fabrication **A** mold was made with the same dimension as that of steel leaf spring. For that reason, mono composite leaf spring with constant width, thickness and constant cross section area was taken throughout. The glass fiber was woven roving type with fiber orientation $[0/45/-45/0]_s$ of 360 GSM was selected. In order to make solution for every 100 parts by weight of epoxy resin and 10-12 parts by weight of hardener 758 is mixed thoroughly at a temperature of 20-40 ^{0}C. During process, wooden mold surface is finished by sand paper and made very smooth. the glass fiber was first sliced to sought in lengths, so that they can deposited on a mold layer by layer according to stacking grouping in order to fabricate mono composite leaf spring. The duration of the process may take 45 min. The mold was allowed to cure.(Figure1) shows A typical fabricated mono composite leaf spring.

Figure1 Mono composite leaf spring

IV. Experimental procedure:

In this, Both the leaf spring s are tested under static loading condition and corresponding deflection and other performance parameters are tabulated in table 2.& 3

4.1 Static analysis of leaf spring : Test equipment used is Servo hydraulic Actuator Test Rig , specification are mentioned below:
Load Cell, HBM, ± 25 kN .



`**Figure 2 .** Servo hydraulic Actuator Test Rig

The deflection of both the spring for comparative study is taken on computerized servo test rig. In experiment analysis the comparative study of e-glass/epoxy and steel leaf spring has been taken. Static strain measurement was carried out using two strain gauge during the stiffness measurement. It was evident from Table.3 load, deflection, and stiffness value during static testing of steel and composite mono leaf spring.

4.4. Finite element analysis of leaf spring

The axle seat is assumed to be fixed and static loading of 2084 N is applied at both end, assume spring as simply supported beam, Both eye ends of leaf spring have flexibility to slide along X direction and as well it can rotate about a pin in Z direction. shown in (Figure3). Therefore, the displacement at both eye ends is constrained along X and Z direction. Since the properties of composite vary with the direction of fiber orientation.

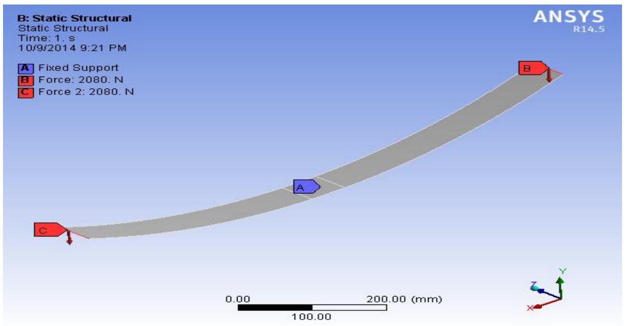


Figure. 3 Loading and boundary condition applied in analysis

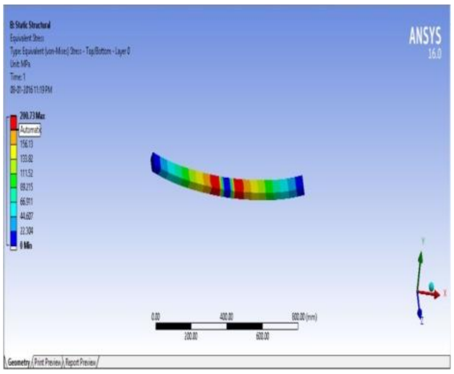


Figure 4. Displacement contour for CLS

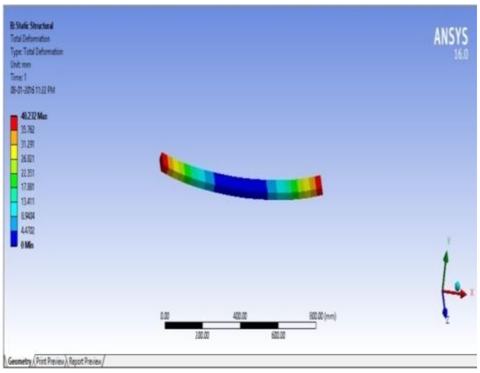


Figure 5. Von Mises Stress distribution for CLS

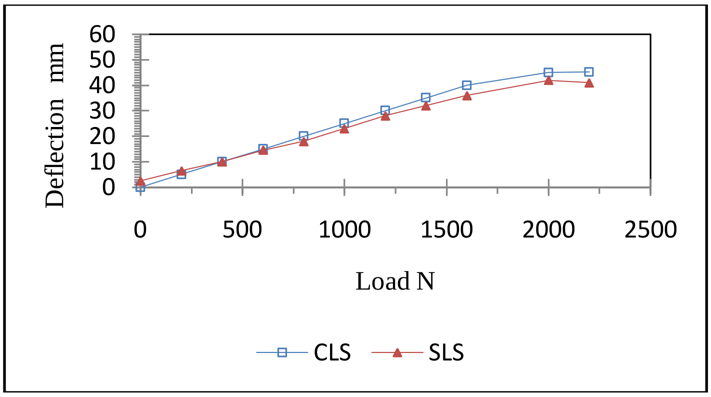


Figure : Load Deflection curve

TABLE 2: Percent saving of weight using composite material

Parameter	Multi steel leaf spring	Composite mono leaf spring	% Weight saving
Weight (kg)	10.5	2.67	74.49

TABLE3: Stress analysis of Multisteel leaf and E-glass/epoxy leaf spring

Parameters	Multi steel leaf spring		% Difference	Composite mono leaf spring		% Difference
	Experiment	FEA		Experiment	FEA	
Load,(N)	2084	2084	Nil	2084	2084	Nil
Maximum Stress (MPa)	480.34	450.38	6.2	211.4	200.7	5.06
Maximum deflection (mm)	44	48	9.0	40	40.22	0.5
Maximum stiffness (N/mm)	44.34	43.41	2.09	52.1	51.81	0.5

4.2Analytical approach for fatigue life assessment of composite leaf spring by Hwang and Han Relation

Hwang and Han have developed an analytical model to predict the number of fatigue cycles to failure for components made up of composite material. [6]

$$\text{Hwang and Han relation : } N = \{ B(1-r) \}^{1/C} \quad \text{.......(1)}$$

Where N= Number of cycles to failure, B=10.33,C=0.142, r = $\sigma_{max} / \sigma_{UTS}$, σ_{max} = Maximum stress, σ_{UTS} = Ultimate tensile strength, r = Applied stress level, above equation is applied for different stress level and fatigue life is calculated for CLS (Table 2). Based on the S-N graph (Fig 6) , it is observed that CLS , which is made up of E-glass fiber/ epoxy is withstanding more than 10,0000 cycle under stress level of 0.43 from Hwang and Han relation. The stress level of 0.43 is obtained is helpful for the determination of remaining number of cycles to failure using fatigue model.[8.]

TABLE 2: Fatigue life at different stress level of composite leaf spring

Maximum stress (MPa)	Applied stress level	Number of cycles to failure N
100	0.1	8143500
200	0.2	3515500
300	0.3	1354800
400	0.4	450900
500	0.5	122700
600	0.6	25000
700	0.7	3200
800	0.8	200

V. Result and discussion

The comparison analysis using experimental & FEA approach between steel leaf spring and composite leaf spring for deflection, stress, stiffness and weight is illustrated in table 3&4 From (Figure 5) shows almost linear characteristic for deflection.. As of the results of static analysis for composite leaf spring, it is seen that the displacement spring is 40 mm which is well below the camber length of leaf spring this point towards 50% enhancement in stiffness shown in table 3. It is observed that the maximum bending stress is about 211MPa. It is seen that for steel leaf spring for stress range of 510MPa, its fatigue life is estimated as 100000 cycles. which is less than fatigue life of composite leaf spring for applied stress level of 0.43.

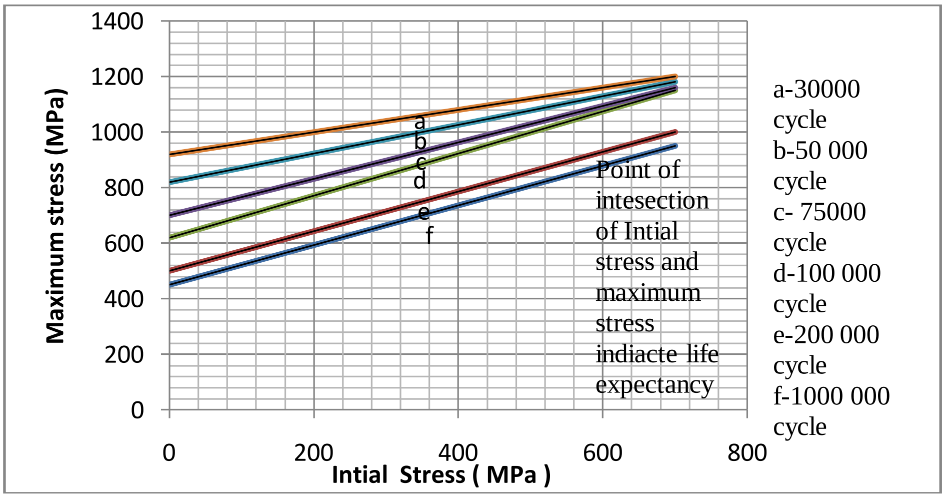


Figure 7: Estimation of fatigue life cycles of steel leaf spring [9]

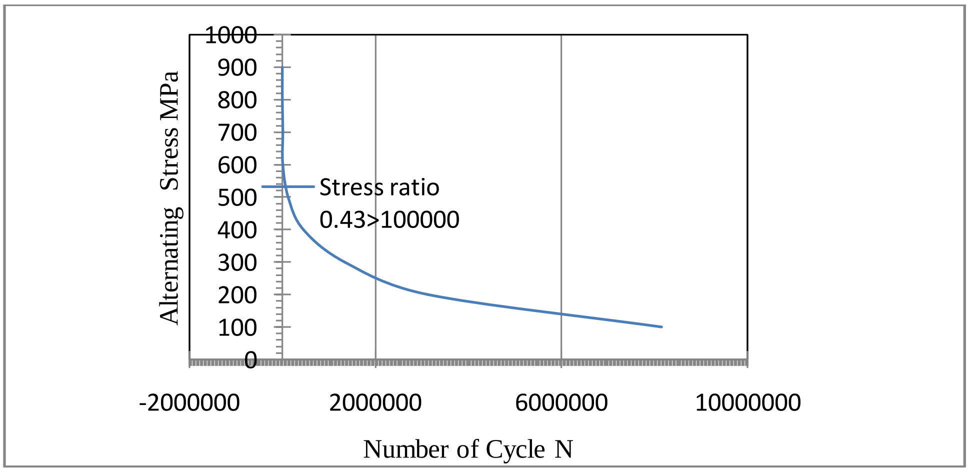


Figure 7: Applied stress Vs Number of cycle

VI. Conclusion

Under the same static loading condition It can be observed from the comparison that the stresses induced in the E-Glass/Epoxy composite leaf spring are less than the conventional steel leaf spring for the same load carrying capacity. The composite mono leaf spring reduces the weight by 74.49% over the conventional leaf spring. In addition to this, the composite leaf spring found higher stiffness than that of conventional leaf spring. Moreover fatigue life of CLS predicted to be higher than that of SLS. So, it is observed that CLS is an effective replacement for the conventional SLS.

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