International Journal of Emerging Engineering Research and Technology
Volume 3, Issue 8, August 2015, PP 154-161
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

Fabrication and Simulation of Composite Sandwich Steel Leaf Spring for Light Commercial Vehicles

P. Manimaran[1] , S. Madhan Raj[2] ,S. Pradeep Devaneyan[3] , D. Peter Pushpanathan[4]

[1, 2, 3, 4] *Department of Mechanical Engineering, Christ College of Engineering and Technology, Moolakulam, Pondicherry*

ABSTRACT

Weight reduction is one of the major concerns of today's automobile world to improve the performance of the vehicles. Therefore light-weight materials have gained more attention. Composites, especially Glass-fibre reinforced composites (GFRC) could be considered a better candidate to replace steel as they possess a high strength to weight ratio and elastic strain energy storing capacity as compared to Steel. As composite materials have become the most preferred in the automobile industry nowadays, an attempt has been made in this work to fabricate a sandwich steel leaf spring coated with E-Glass epoxy composite. The leaf spring made of 55Si2Mn90 steel used in a light commercial vehicle was chosen. Three leaf springs with eyed ends were selected for this study. One of them was uncoated and the other two were coated on either sides with GFRC in different configurations by hand layup technique. The load, deflection and stress variations between the specimens were studied experimentally as well as analytically using CAE. The objective of this work is to reduce the vehicle weight by replacing the laminated steel leaf springs with a single composite leaf spring without losing the comfort and strength.

Keywords: Leafspring,E-glass/epoxy,Composite coating, Static load test.

INTRODUCTION

Leaf springs have been in use for quite a long time in the automobile industry as a shock absorbing component. However, a bulky leaf spring system can take a toll on the vehicle efficiency in terms of load addition and indirectly affect the comfort of the rider. The design and manufacturing processes followed in the automobile sector have been evolving swiftly. In order to keep up with the advancements in this industry, it is imperative to think about the usage of new materials and incorporate new designs. Steel has been the most preferred materials for the fabrication of leaf springs for its superior strength and resilient properties. Some of the commonly used spring materials are SAE-1080, 1095,5155-60, 6150-60 and 9250-60. These steels are initially pre-stressed so as to increase the load carrying capacity of the springs. However, these materials add much weight to the vehicle causing the efficiency of the vehicle to decline. Hence the idea using composites instead of steel in leaf springs came into existence. Composites are known for their high strain energy storing capacity and superior strength to weight ratio [1,2]. The load bearing capacity and the stiffness achieved with a steel leaf spring can also be attained with a composite leaf spring at a lesser weight. However, fabricating a leaf spring completely with composites has its own disadvantages such as poor heat and corrosion resistance. Hence incorporating these two materials together in the leaf spring fabrication would help in capitalizing on the good properties of both materials and negating their disadvantages. Glass fibre has roughly comparable mechanical properties to other fibres such as polymers and carbon fibre. Although not as strong or as rigid as carbon fibre, it is much cheaper and significantly less brittle when used in composites. Glass fibres are therefore used as a reinforcing

Address for correspondence:

jcsmani@gmail.com

agent for many polymer products; to form a very strong and relatively lightweight fibre-reinforced polymer (FRP) composite material called glass-reinforced plastic (GRP), also popularly known as “fiberglass". Many research papers have been published regarding the use of composites in leaf springs. However, the performance of a hybrid composite leaf spring made in these configurations have not been explored yet. Hence in this work, an effort has been to taken to study the effect of the number of laminates above and below the master leaf spring. The effect of e glass epoxy layer thickness in mono composite leaf spring coupled with SAE 1045-450-QT steel on the weight and stress reduction was simulated using ANSYS software [3]. The short term mechanical behavior of both intact and preconditioned glass fiber reinforced composite sandwich ‘I’ beam was investigated under quasi-static loading condition. A high strength and tough epoxy adhesive system was used for bonding the flanges to the web section. It was observed that the ultimate failure such as shear failure occurred in the foam core of the sandwich web. It was concluded that preconditioning the composite beam did not have an overriding effect on mechanical behaviour and thus epoxy adhesive system was proved to be completely adequate [2]. The strength of stainless-steel joints bonded with two epoxy adhesives was investigated by testing the single-lap and butt joints, as well as thick adherent and napkin ring shear tests. The results suggested that the tensile and shear strengths of the epoxy adhesives were quite similar. However, finite element (FE) analyses raised doubts on the true adhesive strengths, due to the complex stress state in joint tests and pressure-dependent adhesive behaviour. In spite of some uncertainties, FE analyses showed that failure could be fairly well predicted by a maximum shear strain criterion [4]. The static and dynamic analyses of steel leaf spring and laminated composite multi leaf springs were done by comparing the displacement, frequencies, deflections and weight savings of composite leaf spring with that of steel leaf spring. The dimensions of an existing conventional steel leaf spring of a Light design calculations. Static and Dynamic Analyses of 3-D model of conventional leaf spring was performed using ANSYS 10.0. A weight reduction of 27.5 % was achieved by using a composite leaf spring [5]. The Optimization of the parabolic mono leaf spring material and the design parameters to attain the lightest spring was studied both theoretically and analytically using FEA [6].

The suitability of natural and synthetic fiber reinforced hybrid composite material in automobile leaf spring application was studied aiming to reduce the weight and thereby the cost. A hybrid composite leaf spring with Jute/E -glass/ Epoxy composite materials was modelled and subjected to the same load as that of a steel spring. Static structural analysis of a leaf spring had been performed using ANSYS 14 and it was found that the laminated hybrid composite leaf spring resulted in considerable weight reduction as compared to its steel counterpart [7]. The stiffness of the steel leaf spring was compared with that of the composite leaf springs made of glass fiber reinforced polymer, carbon epoxy and graphite epoxy resins. The design and analysis of the springs were done using Autocad and ANSYS software respectively [8]. A single leaf, variable thickness spring of glass fiber reinforced plastic (GFRP) with similar mechanical and geometry properties as that of multi leaf steel spring, was successfully designed, fabricated (moulded and hoop wound) and tested. The testing was performed experimentally in the laboratory and was followed by the road test. The performance of the GFRP and the multi leaf steel springs were assessed and compared [9].

MOTIVATION

The extensive literature review suggested that composites are potential candidates to be used in leaf springs instead of steels. The main motivation for this work was derived from the weight savings offered by the composites without compromising on the strength. Composites also possess better fatigue resistance and strain energy thereby providing long service life. Hence, the present work is aimed to design and fabricate a steel-GFRP composite leaf spring which possess the strength, stiffness and load bearing capability comparable to that of steel leaf springs.

TECHNICAL SPECIFICATIONS AND LOAD CALCULATIONS

The steel parabolic leaf spring which could be used for the vehicle with the following specifications was selected for this study.

- **Kerb Weight 840 Kg**

It is the definite weight of the vehicle exclusive of any cargo or passengers on it. It's the basic weight that is used in exclusion to estimate the entire weight of the vehicle with cargo and passengers.

- **Loading Capacity 750 Kg**

It is the maximum load, which can be carried by the vehicle**.**

- **Max Gross Vehicle Weight (Gvw) 1550 Kg**

It is the entire weight of the loaded vehicle. This comprises the vehicle itself and the cargo that is loaded inside that vehicle**.**

The bending stress and deflection due various loads of the selected light commercial vehicle is presented below.

Gross vehicle weight: 1550Kgs

Kerb weight: 840 Kg

Payload: 710 Kg

Acceleration due to gravity (g) =9.813m/s^2

No of leaves = 3

Total weight acting downwards (i.e. at full load) = Gross Vehicle Weight × gravity

= 1550 x 9.81 = 15205.5 N

There are four suspensions two at the front and two at the back. So, Load on one suspension

= 15205.5 / 4

= 3801.4 N or 3800 N approx.

But 2F=3800

F=1900N

Span length, 2L=860mm

L=430mm

Bending stress,

$\sigma b=6FL/3bh^2$

$\sigma b= 433.44$ MPa

Total deflection,

$\delta = 4FL^3/3Ebh^3$

δ =48.81 m

Where,

F= Force (N)

L=span length

σb=bending stress (N/mm^2)

b = breadth of leaf spring (mm)

h = thickness of leaf spring (mm)

E = modulus of elasticity

MATERIAL SELECTION AND PROPERTIES

Many grades of steels such as EN45A, 60Si7, EN47, 50Cr4V2, 55SiCr7, 50CrMoCV4, 65Si7, etc are used as materials for producing parabolic and multi leaf springs. In order for the spring to be more resilient, it must possess high strain energy or in other words, it should have low density and low young's modulus to provide rider comfort. Composite materials have been used lately in leaf springs as they possess some notable properties such as high strength to weight ratio, good damping capability and fatigue strength which are equally good as that of the existing steel materials. Extensive studies have been done on the fatigue behavior of Glass Fiber/Epoxy composites [10, 11]. In this work, the existing parabolic leaf spring of the light commercial vehicle made of 55Si2Mn90 was coated with E-Glass / Epoxy composites.

The properties of 55Si2Mn90 steel and E-Glass / Epoxy material are given in Table 1 and Table 2 respectively.

Table1. *Material Properties of 55Si2Mn90*

PARAMETER	**VALUE**
Young's Modulus (E)	200GPa
Poisson's Ratio	0.3
Tensile Strength Ultimate	1962 MPa
Tensile Strength Yield	1500 MPa
Density	7850 kg/m3
Thermal Expansion	11x10-6 / ^{o}C
PARAMETER	VALUE
Young's Modulus (E)	200GPa
Poisson's Ratio	0.3
Tensile Strength Ultimate	1962 MPa
Tensile Strength Yield	1500 MPa
Density	7850 kg/m3
Thermal Expansion	11x10-6 / oC

Table2. *Orthotropic Properties of E-glass/epoxy material*

PROPERTIES	**VALUE**
Tensile modulus along X-direction (Ex), MPa	3400
Tensile modulus along Y-direction (Ey), MPa	6530
Tensile modulus along Z-direction (Ez), MPa	6530
Shear modulus along XY-direction (Gxy),	2433
Shear modulus along YZ-direction (Gyz),	1698
Shear modulus along ZX-direction (Gzx),	2433
Poisson ratio along XY-direction (NUxy)	0.366
Poisson ratio along YZ-direction (NUyz)	0.217

Poisson ratio along ZX-direction (NUzx)	0.217
Mass density of the material (ρ), kg/mm3	2.6e-6
Tensile strength of the material, MPa	900
Compressive strength of the material, MPa	450
Flexural modulus of the material, MPa	40000
Flexural strength of the material, MPa	1200

MODELING AND ANALYSIS

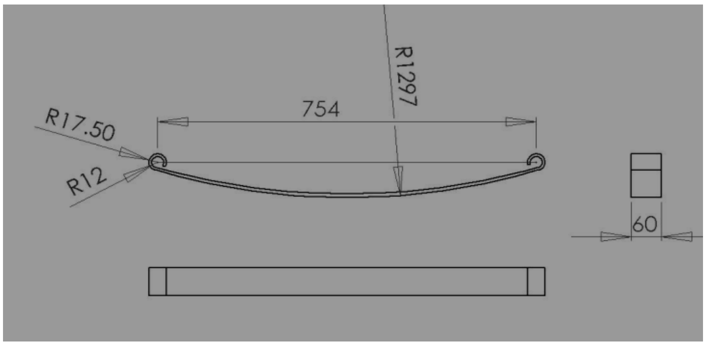

Figure1. *2D Model of master leaf spring*

Solid modeling is a very power tool which has been extensively used in the design and manufacturing of products. In the present work, the solid model of the conventional leaf spring was generated using ProE-4.0 and the analysis was performed using ANSYS 14.5. The dimensions of the leaf spring used in the vehicle are maintained in the modeling process. The 2D and the 3D model of the leaf spring are given in Figure 1 and Figure 2 respectively. The dimensions of the steel parameters are provided in Table.3.

Table3. *Orthotropic Properties of E-glass/epoxy material*

Total Length (L)	930 mm
Number of full length leaves	3
Length of leaf spring from Eye to Eye	754 mm
Thickness (t)	8 mm
Width (b)	60 mm
Load (W) given on leaf spring	3800N

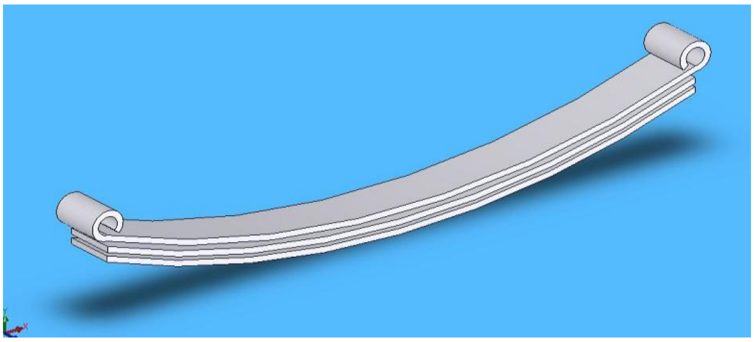

Figure2. *3D Model of master leaf spring*

FINITE ELEMENT METHOD

Static analysis was performed using ANSYS 14.55 on the models created. SOLID45- 3-D Structural element with surface to surface contact was selected. The entire leaf spring was discretized and meshed into 2240 elements with 8120 nodes. The boundary conditions are applied such that the front and rear eyes of the leaf spring are restricted from moving. The mid portion of the leaf spring is fixed so that it oscillates about the center on the application of the load.

EXPERIMENTAL WORK

The leaf spring specimens to be coated were subjected to surface pre-treatment to ensure that the composite coatings stick on to it properly. Proper surface pre-treatment would eventually enhance the joint performance and improve the durability in aggressive environments. The weak oxide layers on the substrate were removed as per the procedures mentioned in ISO 4588. The surfaces were cleaned/degreased by wiping, dipping or spraying. The surfaces were then roughened and subjected to chemical etching to make it chemically active to receive the adherent. The surface pretreated leaf spring was placed on a table. The mixed epoxy resin and the hardener were placed over the leaf spring surface and the glass fibers were place over them. This process was repeated until the desired number of layers was obtained. The composite lay-up was allowed to cure for 24 hours before testing. Three specimens, the uncoated steel leaf spring, specimen 2 – leaf spring coated with composites of 4 layers above 6 layers below and specimen – 3 with 3 layers above and 4 layers below the steel leaf spring were prepared. The specimens prepared are shown in Figure 3.

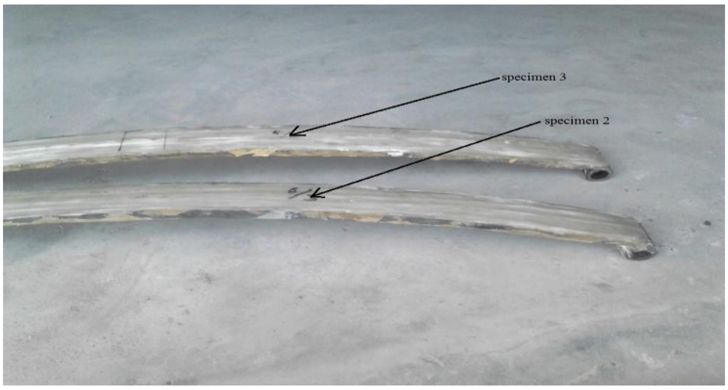

Figure3. *Composite coated leaf springs*

TESTING

The three point bending flexural tests were conducted on the specimen to obtain the modulus of elasticity in bending E_f, flexural stress σ_f, flexural strain ϵ_f and the flexural stress-strain response of the material. The test was conducted in a UTM where the test platform of the machine was extended to accommodate the length of the leaf spring. S-Beam load cell attached to the top plunger of the UTM was used to read the load applied on the springs. Load was applied at the center of the leaf spring. Roller support was mounted to support each eye end so that the leaf spring behaves like a simply supported beam. The loads were applied at intervals in steps of 50kg and the results are presented in Table 3. The central deflection and the breaking point of each specimen were noted down.

Table3. *Simulated stress and deflection values for various loads*

S.NO	Load in kg	Stress in Mpa			Deflection in mm		
		Steel	Composite coated Mono 1	Composite coated Mono 2	Steel	Composite coated Mono 1	Composite coated Mono 2
1	50	285.62	76.673	71.73	4.43	4.10	18.475

2	100	300.15	153.35	133.25	8.8492	14.154	30.648
3	150	315.59	230.02	214.32	13.256	28.307	46.341
4	200	331.63	306	298.21	17.652	42.461	61.295
5	250	348.12	383.36	370.26	22.036	56.615	79.256
6	300	364.79	460.04	445.14	26.409	70.768	89.157
7	350	382.02	536.63	512.36	30.722	84.927	116.4
8	387	395.09	594	583	35	99.076	130.95

RESULTS AND DISCUSSION

The simulated values of deflection and stress for various loads are presented in Table 3. The experimental results were recorded and displayed in Table 4.

Table4. *Experimental stress and deflection values for various loads*

S.N	Load in kg	Load in N	Deflection in mm		
			Steel	Composite coated Mono 1	Composite coated Mono 2
1	50	490.5	4.5	9	8
2	100	981	9	41	36
3	150	1471.5	15.4	49	53
4	200	1962	20	69	75
5	250	2452.5	25.7	84	88
6	300	2943	32	99	111
7	350	3433	36	119	138
8	387	3924	44	133	8

From the results, it could be inferred that the simulated and experimental values are in good agreement and the margin of variation is within the acceptable limits. The weight of the multi-leaf spring used in the light commercial vehicle used in this study was 10.5 Kg. The two composite leaf springs, specimen 1 and specimen 2 prepared for this study weighed 4.5 Kg and 3.92 Kg respectively. It could be inferred from Table 5 that the weight of the leaf spring was reduced by 57.14 % and 62.67 % for Specimen 1 and Specimen 2 respectively.

Table5. *Percentage reduction in weight*

S. No	Specimen	Weight in Kg	% reduction in weight
1	Multi leaf spring	10.5	-
2	Composite Spring Specimen 1	4.5	57.14
3	Composite Spring Specimen 1	3.92	62.67

The stress and the deflection values are found to increase in direct proportion with the load for both steel and composite leaf springs. However, the maximum stress and the deflection induced in the steel and composite springs are found to be well below the permissible calculated levels only up to the load of 250 Kgs. The deflection of the composite springs is found to increase linearly with the increase in load. This behavior seems to be interesting and deserves more attention. In future, this problem could be taken up for and further research could be done to find out the mechanism behind this behavior. However, as far as this work is concerned, it is proved that the composite leaf springs are not inferior to steel leaf springs. It is also noted that the deflection varies between the specimen 1 and specimen 2 with different layering configurations. The defection in fact increases in specimen 2 as compared to steel leaf spring and specimen 1.

CONCLUSION

Two configurations of composite parabolic leaf springs were fabricated and tested experimentally in this work. Also, the 3D models of these springs were simulated using ANSYS.

Composite leaf spring specimens used in this work were proved to be efficient in terms of strength and strain energy storing capacity as compared to their steel counterpart.

Stress and the deflection were found to vary with the change in the number and position of the composite layups.

Increasing deflection of the composite specimens prove that they can withstand high shock loads when used in combination with steel leaf springs.

Using the composite leaf springs instead of multi steel leaf springs reduced the weight by 57.14 and 62.67 % respectively.

Therefore, the idea of using a mono master leaf spring coated with GFRC is proved to be viable and thus can be practically implemented.

REFERENCES

[1] Shishay Amare Gebremeskel "Design, Simulation, and Prototyping of Single Composite Leaf Spring for Light Weight Vehicle" Global Journal of Researches in Engineering Mechanical and Mechanics Engineering Volume 12 Issue 7 Version 1.0 Year 2012, ISSN: 2249-4596 Print ISSN:0975-5861

[2] Mouleeswaran SENTHIL KUMAR, Sabapathy VIJAYARANGAN, "Analytical and Experimental studies on Fatigue Life Prediction of steel and composite Multi-leaf spring for Light Passenger Vehicles using Life Data Analysis" Materials science . vol.13.No.2.2007

[3] B. Raghu Kumar, R. Vijaya Prakash and N. Ramesh, "Static analysis of mono leaf spring with different composite materials", Journal of Mechanical Engineering Research Vol. 5(2), ISSN 2141-2383, February 2013, pp. 32-37

[4] M. M. Patunkar, D. R. Dolas, "Modelling and Analysis of Composite Leaf Spring under the Static Load Condition by using FEA", International Journal of Mechanical & Industrial Engineering, Volume 1, Issue 1-2011

[5] Vijaya Lakshmi, I. Satyanarayana, "Static And Dynamic Analysis On Composite Leaf Spring In Heavy Vehicle", International Journal of Advanced Engineering Research and Studies, E-ISSN2249–8974, Vol. II/ Issue I/Oct.-Dec.,2012, pp. 80-84

[6] J. P. Karthik, K. L. Chaitanya and C. Tara Sasanka , " Fatigue Life Prediction of a Parabolic Spring under Non-constant Amplitude Proportional Loading using Finite Element Method Fatigue Life Prediction of a Parabolic Spring under Non-constant Amplitude Proportional Loading using Finite Element Method", International Journal of Advanced Science and Technology Vol. 46, September, 2012, 143-156

[7] J.A.M. Ferreira a, J.D.M. Costa, P.N.B. Reis, M.O.W. Richardson, "Analysis of fatigue and damage in glass-fibre-reinforced polypropylene composite materials" Composites Science and Technology 59 (1999),1461-1467

[8] Amol Bhanage and K. Padmanabhan, "Design For Fatigue And Simulation Of Glass Fibre/Epoxy Composite Automobile Leaf Spring" Arpn Journal Of Engineering And Applied Sciences, Vol. 9, No. 3, March 2014

[9] D.N. Dubey and S.G. Mahakalkar. 2013. Stress Analysis of a Mono-parabolic Leaf Spring-A Review. International Journal of Modern Engineering Research (IJMER). ISSN: 2249-6645. 3(2): 769-772, MarchApril

[10] B. Raghu Kumar, R. Vijaya Prakash and N. Ramesh. 2013. Static analysis of mono leaf spring with different composite materials. Journal of Mechanical Engineering Research. ISSN: 2141-2383. 5(2): 32-37, February

[11] Shishay Amare Gebremeskel. 2012. Design, Simulation, and Prototyping of Single Composite Leaf Spring for Light Weight Vehicle. Global Journal of Researches in Engineering Mechanical and Mechanics Engineering. 12(7): 21-30.