Design and Fabrication of Hybrid Composite Leaf Spring

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Abstract— This paper describes the design and fabrication procedure of leaf spring using composite material. The automobile industry is constantly focusing on reduction of the weight of un-sprung mass of an automobile without compensating on its performance. The aim of this project is to achieve such a weight reduction in the un-sprung mass of the vehicle i.e. leaf spring without compensating on is load bearing capacity. The project deals with comparing of load bearing capacity, stiffness and weight reduction of composite leaf spring with that of steel leaf spring. The static analysis of the 2-D model of the composite leaf is performed using ANSYS. The FEA results using ANSYS software is compared with the experimental result. Compared to steel leaf spring the composite leaf spring has a stresses and deflection that is much lower and significant weight reduction is achieved.

Key words: Leaf Spring, Composite Material, Steel Leaf, Fea Analysis

I. INTRODUCTION

Composite materials are used to achieve weight reduction by replacing steel with composite so that load bearing capacity is not compensated.

It is possible to achieve the weight reduction with the help of the better quality material, as well as the optimization parameter and better manufacturing processes. Composite materials have been widely used in automobile industry because of its high strength and strength to weight ratio, low cost and elasticity in material and structure design. The leaf spring which is used in automobile for suspension can be replaced with composite since it constitute about 10-25% of unsprung weight. Leaf spring should absorb vertical vibrations due to road irregularities by means of variations in the spring deflection so that potential energy is stored in the spring as strain energy and then released slowly

The composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel. The strain energy in the spring is inversely proportional to density and young's modulus of the material

$$U = \frac{\sigma^2}{\rho E}$$

Where σ is the strength, ρ the density and E the Young's modulus of the spring material, from the above relation it is clear that the material for the spring must have low density and low young's modulus. Composite materials satisfy this condition.

$$S = \frac{\sigma}{2\rho E}$$

Where σ is maximum allowable stress, E is young's modulus and ρ is density. Several papers were devoted to the application of composite materials for automobile leaf spring. Rajendran and Vijayarangan (2001, 2002) studied the application of composite structures for automobiles and design optimization of a composite leaf spring. Sincere effort has been made by many researchers for the application of composite for leaf springs (Daugherty, 1981; Dharam, 1978). Fatigue behaviour of Glass Fiber Reinforced Plastic epoxy (GFRP) composite materials has been studied (Hawang & Han, 1986). Vijayarangan and Ganesan (1994) showed the introduction of fiber reinforced plastics (FRP) which made it possible to reduce the weight of a machine element without any reduction of the load carrying capacity. Since because Fiber reinforced plastics materials have high elastic strain energy storage capacity and high strength-to-weight ratio compared with that of steel, steel springs are being replaced by mono composite FRP leaf springs (Tanabe et al., 1982; Yu and Kim, 1998). Shankar and Vijayarangan (2006) has fabricated and tested the Glass fiber/Epoxy leaf spring with and without bonded end joints and said that around 85% of weight has been reduced. Experimental and numerical analysis are carried out on a single leaf constant cross section composite leaf spring (Dalu & Jadhao, 2011).

Fig. 1: Images of Composite Leaf Springs

II. WORK CONCEPT

A. Objective of the Project

The aim of the research work is to design, analyze, fabricate and test the hybrid combination of woven glass fiber and bi directional fiber Glass Fiber/Epoxy complete composite leaf spring without end joints and composite leaf spring using bonded end joints using hand-layup technique. This is an alternative, efficient and economical method over wet filament-winding technique

B. Selection of Raw Material

The work of the leaf spring is that it must absorb vertical vibrations created due to the surface irregularities of road and to bear the load and provide cushioning effect. This is done by absorbing the vibrations and storing the potential energy in the form of strain energy by leaf deflection and then gradually releasing them, since sudden release may cause cracks and deformation. A material with maximum strength and minimum modulus of elasticity in longitudinal direction is the most suitable material for a leaf spring. . The properties of composite materials that make them suitable for a better replacement for steel leaf in automobile is that

- Higher strength-to-weight ratio,
- Superior fatigue strength,
- Excellent corrosion resistance,
- Smoother ride
- Higher natural frequency.

Fatigue failure is the predominant mode of in-service failure of several automobile components, specifically the springs used in automobile suspension systems. Theoretical equation for predicting fatigue life period, formulated using modulus of fatigue and its degrading rate is simplified by strain failure criterion for practical application.

Considering all these factors Glass Fiber Reinforced Plastic epoxy (GFRP) was chosen for fabrication of the leaf spring.

C. *Hand Layup Technique*

A release agent usually in liquid or semi-liquid (wax) form is applied to the mould. This is done on the mould since to facilitate the removal of the fabricated composite. Then a layer of epoxy resin that is prepared by mixing it with the hardener is applied on the mould followed by positioning of the composite FRP (base material) then it is rolled with the help of hand roller. Again another layer of resin is applied followed by the positioning of the FRP (varying material) and then hand rolling. This is done continues till the required dimensions of the leaf spring is achieved. The pressure that is given is carefully monitored such that it is sufficient enough to completely wet all the FRP. Then enough time is given to ensure that the fabricated specimen is completely cured.

Fig. 2: image of leaf spring with the steel pattern

Fig. 3(a): The woven roll fiber.

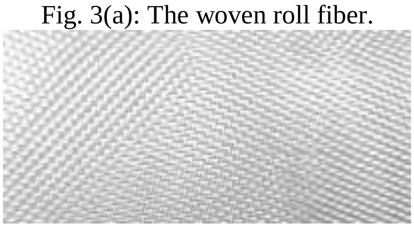

Fig. 3(b): Fiber with 60 degree orientation

III. DESIGN PARAMETER OF STEEL LEAF SPRING

Parameters of the steel leaf spring used in this work are shown in Table 1

Parameter	Value
Material selected – Steel	55Si2Mn90
Tensile strength (N/mm^2)	1962
Yield strength (N/mm^2)	1470
Young's modulus E (N/mm^2)	$2.1 \cdot 10^5$
Design stress (σ_b) (N/mm^2)	800
Total length (mm)	1010
The arc length between the axle seat and the front eye (mm)	595
Arc height at axle seat (mm)	120
Spring rate (N/mm)	32
Normal static loading (N)	2390
Available space for spring width (mm)	60 – 70
Spring weight (kg)	13.6

Table 1: Parameters of steel leaf spring [2]

A. *Selection of Material Sequence and Hybrid Combination of Composite Material for Leaf Spring:*

The sequence of the FRP'S and their types plays a major role in the strength of the composite leaf. Thus two combinations of leaf spring were chosen for the work. The woven glass fiber was fixed as the base FRP (fiber reinforced plastic) owing to its strength and bi-directional fiber of two grades 90^o and 60^o were chosen owing to their flexibility property and two different combinations that were fabricated are as follows:

1) Woven glass + bi- directional fly 90^o
2) Woven glass + bi- directional fly 60^o

These fibers were hybrid using hand lay-up technique. Initially after application of release agent one layer of chopped stand mat was kept for surface finish purpose and then epoxy resin was applied in the surface and then woven glass fiber was cut to the shape of the pattern and placed on the epoxy resin and then they were hand rolled using rollers. Then again epoxy resin was applied on the fiber and then another fiber that is bi- directional fiber was chosen and then cut in the shape of the pattern and placed over the resin layer and hand rolled again . Thus a hybrid layer of various types of glass fibers were formed the fibers being in the order woven glass and bidirectional fly and again woven glass and so on with epoxy resin used in between two layers of fibers and chopped stand mat being use at the top and bottom

Fig. 4: The two leaf springs after fabrication. with dimensions 1. 350mm x 62.17mm x 10.1 mm 2. 350mm x 62.5mm x 9.1 mm (including the 1mm error)

IV. DESIGNS AND FABRICATION OF COMPOSITE MONO LEAF SPRING (MATERIAL SELECTION)

Various types of vehicles that use leaf springs for the suspension were considered for the design parameters of the composite spring. In the composite leaf spring the inter leaf friction plays a major role in determining the wear of the leaf and its failure.

The following dimensions of the leaf spring and the design parameters were considered and the composite leaf was fabricated accordingly.

1) The leaf must have the same strength as that of the conventional steel leaf.
2) The deflection must not exceed the deflection of the steel leaf that is considered.
3) The breadth of the composite leaf must be same as that of the steel leaf to fit perfectly in the jig provided.

The following dimensions of the composite combinations were considered to find out the strength for the better composite material quality.

Composite Specimen	Breadth in mm	Thickness in mm
1. Wovenglass+ bi-directional fly 90^o(specimen-one)	62.17	10.12
2. Wovenglass+ bi-directional fly 60^o (Specimen two)	62.53	9.1

Table 2: Dimensions of the for composite leaf springs

Note: Both leaf springs have a length of 350mm

Sl 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.	Tensile strength of the material, MPa	900
5.	Compressive strength of the material, MPa	450
6.	Shear modulus along XY-direction (Gxy), MPa	2433
7.	Shear modulus along YZ-direction (Gyz), MPa	1698
8.	Shear modulus along ZX-direction (Gzx), MPa	2433
9.	Poisson ratio along XY-direction (NUxy)	0.217
10.	Poisson ratio along YZ-direction (NUyz)	0.366
11.	Poisson ratio along ZX-direction (NUzx)	0.217
12.	Mass density of the material (ρ), kg/mm^3	$2.6\cdot10^{-6}$
13.	Flexural modulus of the material, MPa	40000
14.	Flexural strength of the material, MPa	1200

Table 3: Material properties of E-Glass/Epoxy

A. Specification of the Problem

The specification is to find out which of the following combination of the composite leaf has greater load bearing capacity and bending strength. The test for load bearing capacity and bending strength was performed in UTM machine of 200 KN capacity individually for each of the two leaf springs using single point bending method.

B. Three Point Bending Method

In a three point bending test the specimen to be tested is held in a jig of a UTM and then load is applied in the center and then gradually increased till the breaking point is found out and the corresponding breaking load is noted and tabulated . Initially the specimen one that is woven glass + bi -directional fly 90^o was tested by placing in the UTM and the load was gradually applied till the fracture of the specimen occurred .The same procedure was obtained for the specimen two that is woven glass + bi- directional fly 60^o and the fracture point was noted and resulting load tabulated . For both the specimen chopped stand mat fly was used at the top and bottom to obtain surface finish thus contributing for 1 mm thickness as a whole. Comparing figure 6 &8 it is seen that the bottom side of the spring is subjected to tearing before the upper face of the spring indicating that layer by layer failure taking place.

Fig. 5: The bending test performed in UTM for specimen one

Fig. 6: The broken specimen one after bending test

Specimen	Breaking load in KN	Breaking strength N/mm^2
1) Wovenglass+ bi-directional fly 90^o	7.2	11.44
2) Wovenglass+bi-directional fly 60^o	6.1	10.7

Table 1: This is an example of table title with captions.

Fig. 7: The bending test performed in UTM for specimen two

Fig. 8: The broken Specimens one and two after bending test

V. SUPPORTING CALCULATION

A. For specimen one: Woven glass+ bi-directional fly 90°(specimen-one)

$$Breaking\ strength = \frac{load}{area}$$

$$Breaking\ strength = \frac{7.2 * 10^3}{62.17 * 10.12}$$

$$Breaking\ strength\ = \frac{7200}{629.1604}$$

$$Breaking\ strength = 11.44\ \ N/mm^2$$

1) Notations in Formula:

- Breadth denoted as b
- Thickness as t
- Half of length as L
- Load applied as W
- Young's modulus as E

a) Moment of inertia 'I":

$$I = \frac{bt^3}{12}$$

$$= \frac{60*10.12^3}{12}$$

$$I = 5369.59\ mm^4$$

b) Design (or) working stress obtained:

$$\sigma_b = \frac{6WL}{bt^2}$$

$$= \frac{6*7.2*1000*175}{62.17*10.12^2}$$

$$\sigma_b = 1187.35\ N/mm^2$$

c) Deflection (δ):

$$\delta = \frac{WL^3}{3EI}$$

$$= \frac{7.2*1000*175^3}{3*15.68*10^3*5369.59}$$

$$\delta = 152.25\ mm$$

B. For specimen one: Woven glass+ bi-directional fly 60° (specimen-two)

$$Breaking\ strength = \frac{load}{area}$$

$$Breaking\ strength = \frac{6.1 * 10^3}{62.53 * 9.1}$$

$$Breaking\ strength\ = \frac{6100}{569.023}$$

$$Breaking\ strength = 10.7\ \ N/mm^2$$

1) Moment of inertia 'I":

$$I = \frac{bt^3}{12}$$

$$= \frac{62.53*9.1^3}{12}$$

$$I = 3926.73\ mm^4$$

2) Design (or) Working Stress Obtained:

$$\sigma_b = \frac{6WL}{bt^2}$$

$$= \frac{6*6.1*1000*175}{62.53*9.1^2}$$

$$\sigma_b = 1005.9\ N/mm^2$$

3) Deflection (δ):

$$\delta = \frac{WL^3}{3EI}$$

$$= \frac{6.1*1000*175^3}{3*15.68*10^3*3926.73}$$

$$\delta = 176.7\ mm$$

VI. FINITE ELEMENT ANALYSIS

Finite element analysis was performed by creating a model of the steel leaf in PRO-E 4.0 and importing the image to ANSYS 10.0 analysis software. Solid 46 was selected. Since the properties of composite leaf spring vary with the variation of the direction of the fibers, the loading conditions were assumed to be static. The load was applied at the center and the FEA results were obtained. In finite element analysis the original component is broken down into small components and forces and its resultant stress on these components are studied and result is generated resulting in accuracy and precision of the results.

Fig. 9: The finely meshed leaf solid in ANSYS

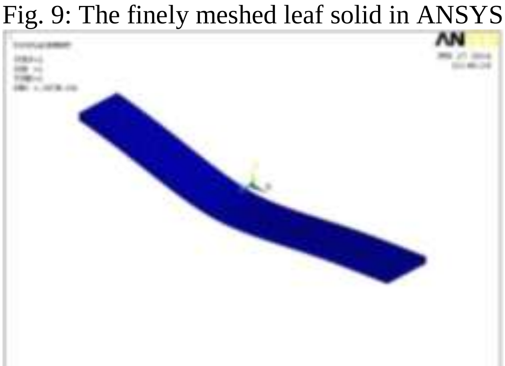

Fig. 10: The Displacement of the leaf when the load is applied at the center

Fig. 11: The comparison between the initial and the displaced position

In the above FEA analyzed result the difference between the initial and the final position of the leaf before and after the application of the load at the center is shown and can be noted that the edges are held and the load is greater at the center of the leaf.

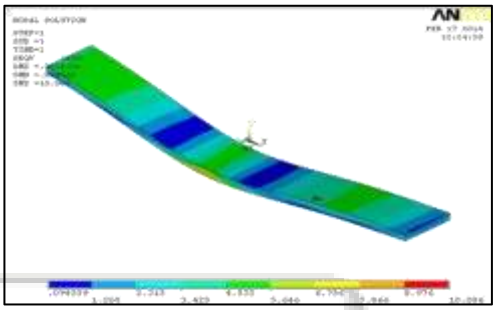

Fig. 12: The ANSYS result for the stress distribution zones on the composite leaf. Blue colour indicates very less stress region and the intensity and magnitude of stress increases from DARK BLUE TO RED.

The stress distribution on the composite leaf is found to be higher at the center (RED at the bottom face) and it can be inferred that the stress is accumulated at the point of static loading on the leaf owing to the heterogeneous nature of the composite leaf.

The FEA analysis for the composite leaf revealed that the stress developed at the center that is at the point of application of load is almost equal to that of the experimental value.

1) Stress developed at the center by FEA method was found to be =10.086.
2) This value is in accordance with the experimentally calculated value which is =11.44.

The finite elemental analysis of the steel leaf for the same dimension was performed ANSYS10.0 and the result was obtained.

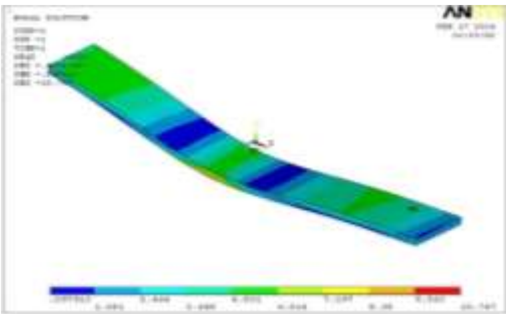

Fig. 13: The ANSYS result for the stress distribution on the steel leaf.

The FEA analysis of the steel leaf revealed that the stress developed in the steel leaf at the center is equal to 10.747.

Stress developed in N/mm^2	steel	E-GLASS/ EPOXY composite
	10.747	10.086

VII. INFERENCE AND DISCUSSIONS

From the above experimental investigation it is inferred that

1) The stress developed in the FRP composite leaf spring is less than that of the steel.
2) FRP is much lighter in weight and thus increases the mileage of automobiles.

VIII. CONCLUSION AND RESULT

– The application of composite material for the automobile leaf spring is found be an effective method to reduce the unsprung mass of the automobile to increase the fuel efficiency and to increase the life span of the spring.
– The two FRP combination chosen was found to have almost same stress distribution but the combination of Wovenglass+ bi-directional fly 90^o was experimentally found to have superior breaking strength and lesser rate of deflection than that of the second hybrid Wovenglass+ bi-directional fly 60^o

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