OPEN ACCESS
International Journal Of Modern Engineering Research (IJMER)

Analysis of GFRP Leaf Spring

Akhil Mehndiratta[1], Nand Kishore Singh[2], Kalyan Kumar Singh[3]
*(Mining Machinery Engineering, Indian School of Mines, Dhanbad, India)
** (Mechanical Engineering, Indian School of Mines, Dhanbad, India)
*** (Mechanical Engineering, Indian School of Mines, Dhanbad, India)

ABSTRACT: *Light-weight structure utilizing novel design and advanced materials is one of the keys to improving the fuel efficiency and reducing the environmental burden of automotive vehicles. The automobile industry has shown increased interest in the replacement of steel leaf springs with fiberglass reinforced composite leaf springs. The current paper focuses on the analysis, design and fabrication of GFRP composite leaf spring. The paper delineates static analysis of steel leaf spring and laminated composite Multileaf spring. The objective is to compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring using theoretical, experimental and numerical analysis. CATIA software is used for modelling and static analysis of 3-D model of conventional leaf spring is performed using ANSYS 14.0. A weight reduction of 86.424 % is achieved by using composite leaf spring.*
Keywords: *GFRP, Leaf Spring, Static Analysis, Weight Reduction*

I. Introduction

Traditional leaf springs used in vehicles are made of mild steel, which is heavy in weight. A leaf spring of reduced weight, without compromising stiffness can increase the efficiency of vehicle. Hence, composites can be used as an alternative to traditional engineering materials for leaf spring. S. Vijayarangan et.al. [1] showed the introduction of fibre reinforced plastics (FRP) made it possible to reduce the weight of a machine element without any reduction of the load carrying capacity. Because of FRP materials high elastic strain energy storage capacity and high strength to-weight ratio compared with those of steel, multi-leaf steel springs are being replaced by GFRP leaf springs. Ballinger C.A. [2] – Getting Composites into Construction, Reinforced Plastics, 1995. Composite leaf spring in the early 60 failed to yield the production facility because of inconsistent fatigue performance and absence of strong need for mass reduction. Particularly the automobile manufacturers and parts makers have been attempting to reduce the weight of the vehicles in recent years. Studies are made to demonstrate viability and potential of FRP in automotive structural application. H.A. Al-Qureshi et. al. [3] study on the analysis, design and fabrication of composite springs. From this viewpoint, the suspension spring of a compact car, “a jeep" was selected as a prototype. A single leaf, variable thickness spring of glass fibre reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf steel spring, was designed, fabricated (moulded and hoop wound) and tested. The testing was performed experimentally in the laboratory and was followed by the road test. Moris [4] concentrated on using composites in the rear suspension system. Shivashankar, Vijayarangan, and Pradeep [5] stated that taking the advantages of mass production and continuous fibre accommodation, composite leaf spring with constant cross sectional area is designed using Genetic Algorithm (GA) method. The weight of the composite leaf spring can be reduced by 53.5% by applying the GA optimization technique. Composite mono leaf spring reduces the weight by 85% for E-Glass/Epoxy over conventional leaf spring. The reduction of 93% weight is achieved by replacing conventional steel spring with an optimally designed composite mono-leaf spring. Daugherty [6] studied the application of composite leaf spring in heavy trucks. Corvi [7] investigated a preliminary approach to composite beam design and used it for a composite leaf spring. Breadmore [8,9] studied the application of composite structures for automobiles. Yu and Kim [10] designed and optimized a double tapered beam for automotive suspension leaf spring. Another composite suspension of circular and elliptic rings have been invented and examined experimentally and theoretically by Charrier et al. [11,12]. However in recent years, great effort has been made by automotive industry in the application of leaf springs made of composite materials. For such application, graphite/epoxy composite demonstrates its superiority over other composites. Due to availability and cost limitation, in the present work we have used Plain woven glass fiber (300 gsm) having fibers at 00 and 900 direction, and steel net is used as reinforcement in resin (mixture of epoxy-L12, liquid epoxy resin based on bisphenol-A and hardener-K6, N,N'-Bis (2-aminoethyl) ethane-1,2-diamine in mass ratio of 100:10).

II. THE DESIGN PARAMETER

Springs are designed to absorb and store energy and then release it. Hence, the strain energy of the material becomes a major factor in designing the springs. Leaf springs also known as flat spring are made out of flat plates. During normal operation, the spring compresses to absorb road shock. The leaf springs bend and slide on each other allowing suspension movement. The relationship of the specific strain energy can be expressed as

$U = σ^2/ p E$ (1)

Where σ is the strength, p the density and E the Young's modulus of the spring material. Material having lower modulus and density will have a greater specific strain energy capacity. Therefore, the introduction of composite materials made it possible to reduce the specific weight of the leaf spring without any reduction on load carrying capacity and stiffness. In the present work, the following parameters are considered in the modelling of leaf spring: total length (eye to eye), 60 mm; arc height of axle seat (camber) 10 mm; width of leaves 50mm; thickness of leaves 4 mm: full bump loading 1842 N.

III. PROTOTYPE MANUFACTURING

In the present work, Hand-lay-up method was used to manufacture the prototype of a composite leaf spring followed by Vacuum Pressing. Using plywood as a mold material, prototype was fabricated as per desired dimension. The glass fibers were cut to desired length so that they could be deposited on mold layer-by-layer during fabrication of composite leaf spring. The solution of epoxy resin and K6 Hardener was prepared. The fabric was impregnated with epoxy resin. A releasing agent (gel/wax) was applied uniformly to the mold, to obtain good surface finish. This was followed by uniform application of epoxy resin over glass fiber. First layer of glass fiber was placed on mold followed by epoxy resin solution. Another layer was layered and epoxy resin was applied and a roller was used to remove all the trapped air. The same procedure was repeated till the desired thickness was obtained. Vacuum Pressing was done for half an hour with Vacuum Pressure of 700 Hg. Care must be taken during the individual lay-up of the layers to eliminate the fiber distortion, which can result in lowering the strength and rigidity of the spring as a whole. The mold was allowed to cure about 4-5 days at room temperature. The leaf spring was removed (as shown in Figure 1) from the mold finally and the excess material was trimmed which is shown in Figure 2.

Lay-up: $(4G^{0,90}/ \text{steel net}/4G^{0,90})$

where, $G^{0,90}$ = Plain woven glass fabric having fiber in 0^0 and 90^0 direction.

Fig.1 Prototype manufacturing setup

Untrimmed leaf Trimmed leaf

Fig.2 Untrimmed and Trimmed prototype of GFRP leaf

IV. EXPERIMENTAL ANALYSIS

As leaf spring can be treated as a simply supported beam, so Compression test of GFRP composite leaf spring was performed in UTM H50KS manufactured by Hounsfield to find out its deflection, stiffness and load carrying capacity as shown in Figure 3.

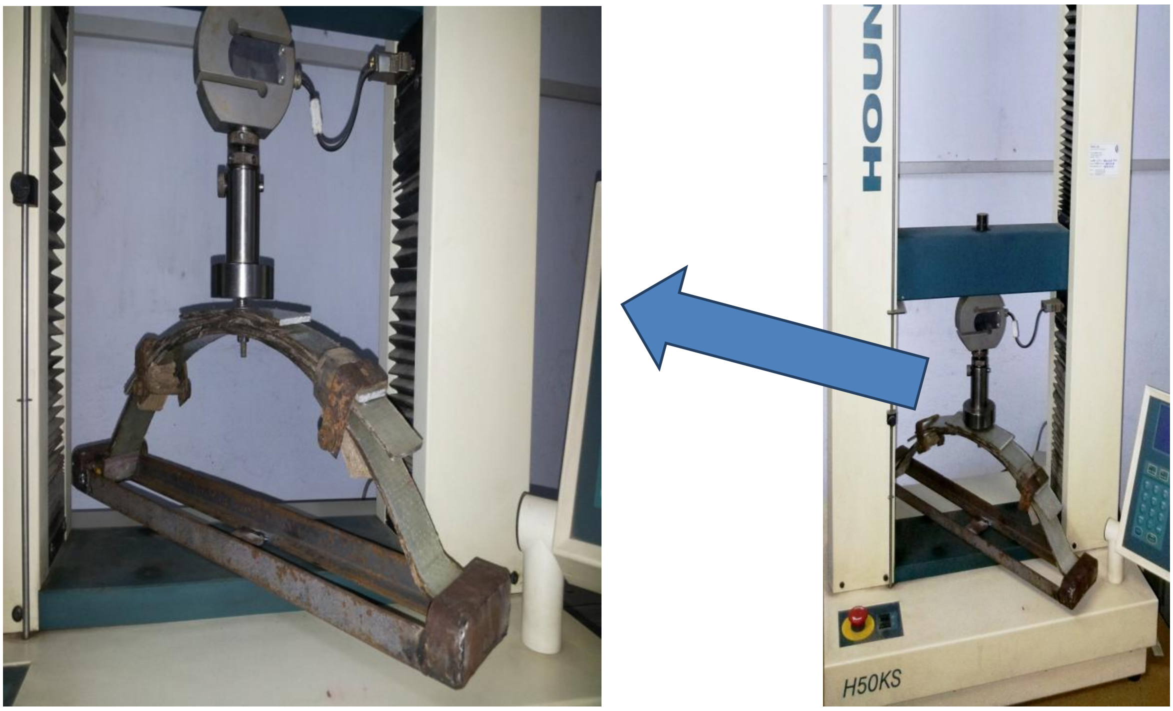

Fig.3 Experimental setup for compression test

V. NUMERICAL ANALYSIS

For modelling of leaf spring CATIA software is used and FEA (Finite Element Analysis) of point loading on the leaf spring made of GFRP is simulated by ANSYS 14.0 for static loading. The leaf spring was modelled with tetrahedron mesh (as shown in figure 4) using MAT_022 which is used for composite material and MAT_01 is the isotropic elastic material card which is used for steel net used in proposed leaf spring. The force (loading) was simulated to act along y-direction by assigning the mode in prescribed motion. In the simulation, the loading is being started with the surface to surface contact between two leaves of the spring and gradually is progressed to tight surface to surface contact between the layers of one leaf. Automatic surface-to-surface contact is employed to simulate the contact between the axle and different blades of the spring.

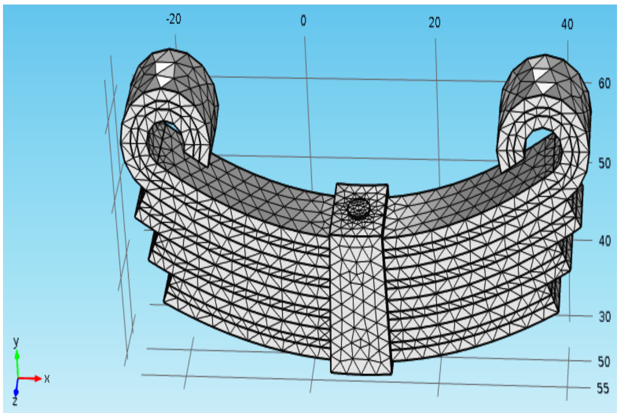

Fig.4 Meshing of leaf spring

VI. RESULTS AND ANALYSIS

The performance of an existing multileaf mild steel spring was compared with the fabric glass/epoxy multileaf spring.

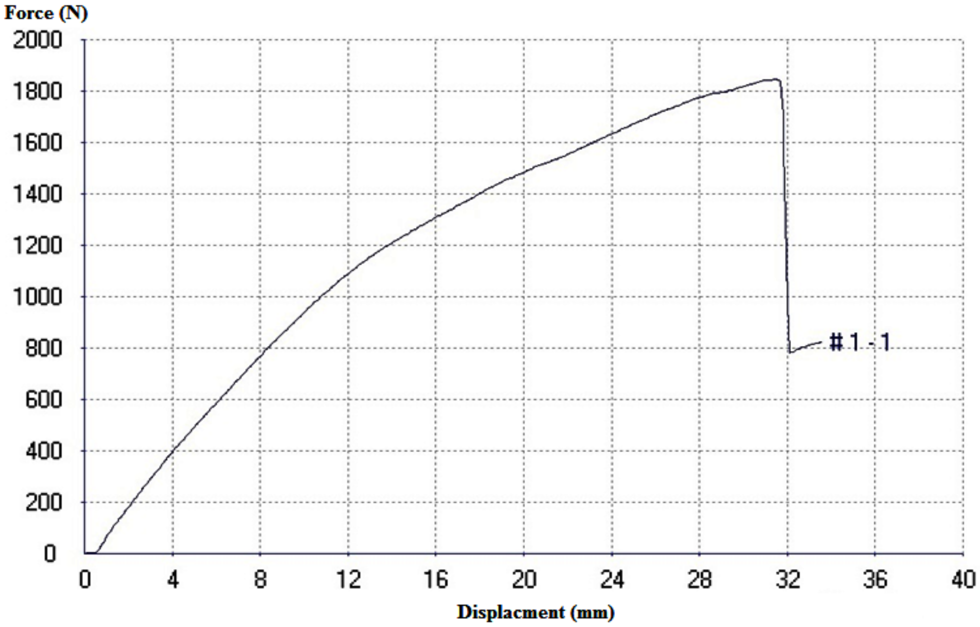

Fig.5 Force- Displacement graph of prototype (leaf spring of GFRP) – Experimental

As shown in figure 5, the maximum load taken by proposed leaf spring was 1842 N and maximum deflection of proposed leaf spring was 32 mm which is 13.513 % less than the leaf spring of Mild steel (evaluated theoretically). As shown in table 1 the proposed leaf spring is carrying the same load and it has 86.424 % reduced weight.

Table 1

GFRP leaf spring-(Experimental)	Mild Steel leaf spring-(Theoretical)
Maximum Load = 1842 N **Maximum Deflection = 32 mm**	**Maximum Load (2W) = 1842 N** **Maximum Deflection =** $\frac{4WL^3}{nEbt^3}$ **□ 37 mm** **Where,** **E(Young's modulus) = 2.1X10**^{11} **N/m**^{2} **2W(Maximum Load)= 1842 N** **t(thickness of the leaf) = 4 mm** **2L(Horizontal Distance) =60cm** **n(no. of leaf) = 4** **b(width of the leaf) = 5 cm**
Weight = 0.765 kg	**Weight = 5.635 kg**
% reduction of weight = 86.424 % and % reduction of deflection = 13.513 %	

6.1 Numerical Analysis

Figure 6 depicts the maximum principal stress and Figure 7 shows the total deformation respectively of the GFRP leaf spring when a static load is applied. Figure 8 describes the variation of Deformation in the GFRP leaf spring with the load applied on it.

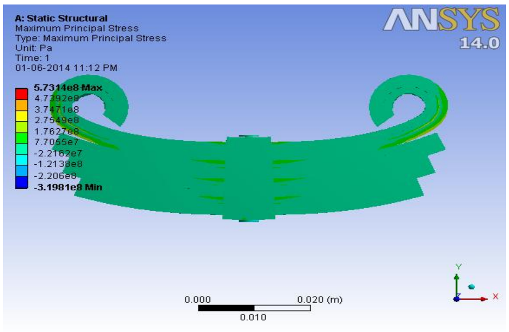

Fig.6 Stress distribution analysis

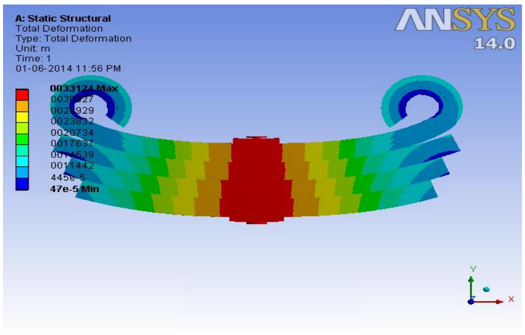

Fig.7 Total Deformation analysis

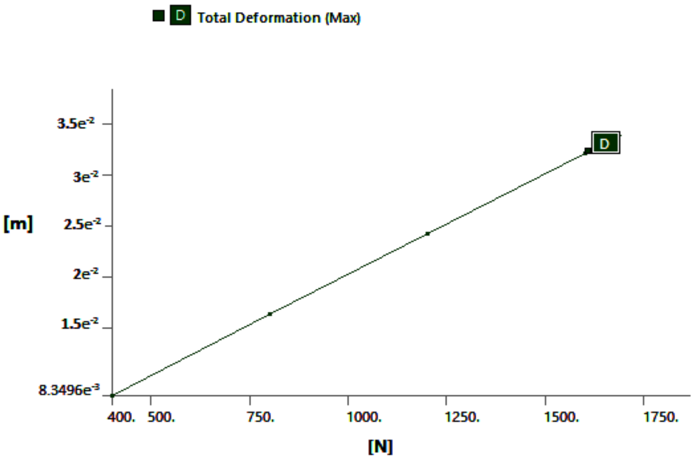

Fig.8 Deformation - Force graph

Table 2 shows the comparison between Experimental and Numerical analysis results of GFRP leaf spring. Figure 9 shows the failure of master leaf due to the compression test performed on GFRP Leaf spring.

Table 2

Experimental (GFRP leaf spring)	**Numerical (GFRP leaf spring)**
Displacement = 32 mm	**Displacement= 30.5 mm**
Maximum load carrying capacity = 1842 N	**Maximum load carrying capacity =1675 N**

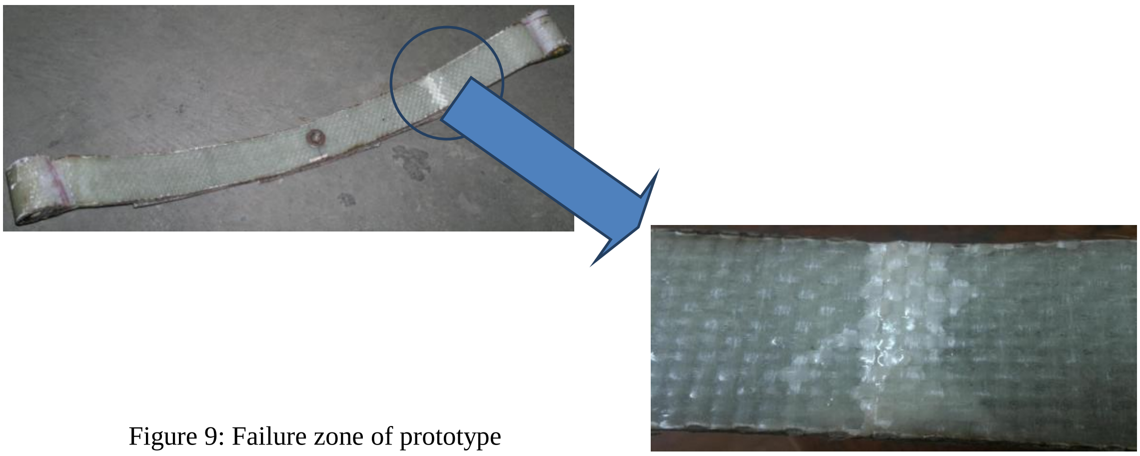

Figure 9: Failure zone of prototype

The comparison of cost of GFRP leaf spring and Mild Steel leaf spring is shown in Table 3.

Table 3

GFRP Leaf Spring	**Mild steel leaf spring**
Price of raw material utilized for each blade: **Plain woven Glass fiber (300 gsm) = 24.8 INR** **Hardener (K6) = 25 INR** **Epoxy (L12) =100 INR** **Miscellaneous =110 INR** **Total = 259.8 260 INR**	**Market price of each blade (Jamna Auto Industries Ltd.): 600 INR**
% reduction of price per blade = 56.66 %	

VII. CONCLUSION

A Comparison has been made between laminated composite leaf spring & steel spring having same design and same load carrying capacity

- Leaf spring made of GFRP and mild steel have:
  - ❖ Same deflection under same load.
  - ❖ Similar bending stress.
- GFRP leaf spring is 86.424 % lighter than leaf spring of mild steel.
- GFRP blades are 56.66 % cheaper than mild steel blades.

REFERENCES

[1] S. Vijayarangan, Rajendran, Design and Analysis of a Composite Leaf spring, *Journal of Institute of Engineers India*, 2002.

[2] Ballinger C.A. – Getting Composites into Construction, *Reinforced Plastics*, 1995.

[3] AL-Qureshi, H. A. Automobile leaf springs from composite materials, *Journal of Processing Technol.*,2001.

[4] Morris CJ. Composite integrated rear suspension. *Comp Struct 1986; 5: 233–42*.

[5] D. Rajiv R. Pradeep G.S. Shivashankar, S. Vijayarangan, Genetic Algorithm Based Optimal Design of Mono Composite Leaf Spring and Testing, *International Journal of Modern Engineering Research* (IJMER) *Vol.2, Issue.4*, 2007.

[6] Daugherty RL. Composite leaf springs in heavy truck applications. In: *Composite Materials,Proceedings of Japan–US Conference, Tokyo, 1981, p. 529–38*.

[7] Corvi A. A preliminary approach to composite beam design using fem analysis. *Comp Struct 1990;16: 259–75*.

[8] Beardmore P, Johnson CF. The potential for composites in structural automotive Applications, *Comp Sci Technol 1986; 26: 251–81*.

[9] Beardmore P. Composite structures for automobiles. *Comp Struct 1986; 5: 163–76*.

[10] Yu WJ, Kim HC. Double tapered FRP beam for automotive-suspension leaf spring, *Comp Struct 1988; 9: 279– 300*.

[11] Charrier JM, Cloutier A, Comte R, Connolly R, Limoges R. Fabrication and testing of hollow reinforced plastic (RP) beams of circular and elliptic cross sections. In: *Proceeding of 40th annual conference SPI Paper* 5-D; 1985.

[12] Charrier JM, Connolly R, Maki SG, Plourde MA. End loading of filament wound circular and elliptic FRP rings-spring element applications. In*: Proceeding of 41st annual conference. SPI Paper* 24-B; 1986.

[13] Hart-Smith LJ. Mechanically fastened joints for advanced composites, phenomenological consideration and simple analysis, *Fibrous Composites in Structural Design, Premium Press,1993.*

[14] R.S. Khurmi, J.K. Kupta. *A text book of Machine Design,* 2000, Chapter. 23, Page. No (866-874).

[15] R. M. Jones, *Mechanics of Composite Materials*. 2e, McGraw-Hill Book Company, 1990.

[16] K. Tanabe, T. Seino, Y. Kajio, *Characteristics of Carbon/Glass Fiber Reinforced Plastic Leaf Spring, 1982.*

[17] Mallick DK, editor. *Composite engineering handbook*. Marcel Dekker; 1997. p. 720–36.