Middle-East Journal of Scientific Research 24 (S1): 05-10, 2016
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2016.24.S1.3

Analysis of Hybrid Fiber Composite Mono-leaf Spring for Automotive Suspension

G. Gnanakumar, R. Vijayakumar and T. Rajendiran

Department of Mechanical Engineering, Panimalar Institute of Technology,
Poonamallee, Chennai – 600123, Tamil Nadu, India

Abstract: Leaf spring is one of the main components and it provides a good suspension. It plays a vital role in automobile application. It withstands lateral loads, brake torque, driving torque in addition to shock loading. The present invention relates to motor vehicle rear wheel suspension systems. Even though there are many different types of rear suspension systems available for use in motor vehicles, the conventional leaf spring is most widely used. In rear-wheel drive vehicles, during acceleration the leaf spring is subject to twisting forces which are opposite in direction and magnitude to the acceleration of the drive wheels. Due to this repeated twisting and untwisting, bending moment is produced at the middle of the leaf spring. The forces does not affect the neutral axis but the portion below the neutral axis if affected by compressing load and above the neutral axis is affected by tension load. Other suspensions can be used which provide sufficient strength under such conditions. Multi leaf spring provides additional strength, but lack of flexibility and increase the overall weight of the vehicle. In this regards, there is a need for a leaf spring assembly which provides high-strength to weight ratio while being simple in design and low cost and also needed a leaf spring assembly which is readily interchangeable to alter the suspension qualities of the assembly. The current innovation to fulfill the need of enhancing the fatigue behaviour along with weight reduction through carbon fibers mixed with glass fiber in polymer matrix[8]. This process is called hybridization.

Key words: Leaf spring · Loading · Fiber material

INTRODUCTION

Investigation of composite leaf spring in the early 60's failed to yield the production facility because of inconsistent fatigue performance and absence of strong need for mass reduction. Researches in the area of automobile components have been receiving considerable attention now. 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. Based on consideration of chipping resistance base part resistance and fatigue resistance, a carbon glass fiber hybrid laminated spring is constructed. The composite leaf springs have better fatigue behavior than steel leaf springs. The hybridization technique is used effectively to improve fatigue behavior and weight reduction properties. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. It is well known that 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. The relationship of the specific strain energy can be expressed as

$$U = ½ (σ^2 /E)$$

where
σ- Strength,
ρ- Density and
E - Young's modulus of the spring material.

The introduction of composite materials was made it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. Since the composite materials have more elastic strain energy and high strength to weight ratio as compared to those of steel. And also the fatigue strength is increased by incorporating carbon fibers with glass fiber reinforced

Corresponding Author: G. Gnanakumar, Department of Mechanical Engineering, Panimalar Institute of Technology, Poonamallee, Chennai – 600123, Tamil Nadu, India.

plastics (GFRP). Here E-glass continuous fiber (13 to 23ìm) and carbon fiber of10 to 15 percentages (by weight) is used as reinforcement in polymer matrix. Epoxy resin, excellent in strength and weather resistance, is mainly used as the matrix resin for FRP. As for CFRP spring, leaf springs composed of high strength, High-modulus continuous polyacrylonitrile-based carbon fiber (5 to 10 ì m)and epoxy resin is the typical product. By virtue of high-specific strength, high-specific modulus and excellent fatigue resistance, the CFRP spring has a remarkable feature of light weight, compactness and long service life. It has an added advantage of dimensional accuracy, chemical resistance and complex shape.

Material Composition of Frp Spring: FRP springs are composed of fiber and matrix resin. The properties of the springs are mostly governed by the mechanical property of fiber material. On the other hand, the matrix resin has the secondary properties such as environmental resistance and durability of springs. Moreover, the bonding quality of fiber and resin has a key role of spring characteristics. High tensile strength and high modulus of elasticity are regarded as the most popular merit of FRP springs. Therefore, glass fiber and/ or carbon fiber have been selected as a suitable fiber material to the spring application. Matrix resin, though it has only a secondary role for the mechanical property of the spring, governs the property of toughness, heat-resistance, moisture resistance, oil resistance and fatigue resistance, etc. Generally, epoxy resin is widely used. The present research limited to design of hybrid mono leaf spring and analyzed by using ANSYS 12software and experimental work. In which the model is created by AUTO CAD and it is imported to ANSYS work bench. While adding carbon fiber in glass fiber reinforced plastic the Young's modulus and ultimate stress value will begetting varied. The Young's modulus value has assumed as $92x10^3$ N/mm^2 based on previous research. In steel multi leaf spring design the maximum bending stress is given by

$\sigma_b = 1.5WL / nbt^2$ [5]

where

σ_b = Maximum bending stress
W = Load applied at the eye piece
L = Length of the leaf spring from center to eye piece
n = Number of leaf spring
b = Width of the leaf
t = Thickness of the leaf

With the help of maximum bending stress and maximum deflection value, width and thickness has calculated by trial and error method.

Literature Survey: All the literatures reported that the cost of composite leaf spring is higher than that of steel leaf spring. Hence an attempt has been made to fabricate the composite leaf spring with the same cost as that of steel leaf spring. Some of these papers are reviewed here, with emphasis on these papers that involve composite leaf sprigs E. Made, B.B. Sahri, G. Goudah [1] concluded that it is essential for the composites to control the failure by utilizing their strength in principal direction instead of shear during the suspension. The fatigue life was expressed in terms of the damage that is done to the structure by a prescribed loading sequence or as the number of repeats of the sequence that will cause failure of the structure. I.Rajendran, S.Vijayarangan [2] investigated the flexural rigidity is an important parameter in the leaf spring design and it should increase from two ends of the spring to its centre. This idea gives different types of possibilities namely- Constant cross-section design, constant width varying thickness design and constant thickness with varying width design. The constant cross section design is selected to accommodate continuous reinforcement of fibers and also formats production. The design of composite leaf spring aim sat the replacement of multiple leaf springs of an automobile with a mono-composite leaf spring. Abdul Rahim, Abu Talib, Aidy Ali,NurAzidaCheLah [3] explains Modal analysis of composite based elliptic spring for automotive applications. Experimented modal analysis in structural mechanics is to determine the natural shapes and frequencies of an object or structure modes. Modal analysis techniques have arisen a san alternative to solving the full set of (n)equations for (n) unknown displacements. ErolSancaktar, Mathieu Gratton [4] designed a new model to reduce the strain on outer fibers by atonal of four leaves, two on each side of the strut. The crosshatched part consist of thin laminated plates with a central hole. These plates are used to keep the leaves in position around the strut. By tapering the leaves in the thickness direction as well as in the width direction towards the ends, an even distribution of stresses can be achieved providing efficient material usage. Beardmore [5] investigated the utilization of glass reinforced epoxy resin for composite leaf spring application's. Subramanian, S. Senthilvelan [6] reported the influence if reinforced fiber length on the performance of injection molded

Table 1: Properties of glass fiber

PARAMETER	VALUE
Material selected	E-Glass
Tensile Strength (N/mm^2)	3445
Young's modulus *E* (G Pa)	50
Design stress [σ_b] (N/mm²)	1264
Total length (mm)	1000
Normal Static Loading (Kg)	362

thermoplastic leaf spring joint. Gulursiddaramanna Shivashankar [7] explained that when compared to steel spring, the composite spring has stresses that are much lower, the natural frequency is higher and the spring weight is nearly 85% lower with bonded end joint and with complete eye unit.H.A. Al-Qurush [8] explained, the leaf spring model was considered to be a parabolicallytapered, constant width beam carrying a concentrated load and assumed to be symmetrical with different cord lengths for the two limbs of the spring and to enhance fatigue behavior could be improved by hybridization, in which various amounts of carbon and glass fibers are combined. Considering several types of vehicles that have leaf springs and different loading on them, various kinds of composite leaf spring have been developed. In some designs the thickness and width of the spring are fixed along the longitudinal axis [11]. In some types, the width is kept constant and thickness is variable along the spring [12]. In other types width is fixed and in each section the thickness is varying hyperbolically so that at two edges the thickness is minimum and in the middle is maximum [13]. Another design the width and thickness are fixed from eyes to the middle of spring and towards the axle seat the width decreases hyperbolically and thickness increases linearly [14]. In their design the curvature of spring and fiber misalignment in the width and thickness direction are neglected. General discussion on analysis and design of constant width, variable thickness composite leaf spring is presented. The various properties of Eglassfibreis given in Table 1.

Carbon Fibre: Carbon fiber, alternatively graphite fibre,carbon graphite or CF, is a material consisting of extremely thin fibers about 0.005–0.010 mm in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment makes the fiber very strong for its size. Several thousand carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric. The density of carbon fiber is also considerably lower than the density of steel, making it ideal for applications requiring low weight. The properties of carbonfibre such as high tensile strength, low weight and low thermal expansion make it very popular in aerospace, civil engineering, military and motorsports, along with other competition sports. However, it is relatively expensive when compared to similar materials such as fiberglass or plastic. Carbon fiber is very strong when stretched or bent, but weak when compressed or exposed to high shock (e.g. a carbon fiber bar is extremely difficult to bend, but will crack easily if hit with a hammer).Tensile strength and modulus are significantly improved by carbonization under strain when moderate stabilization is used. X-ray and electron diffraction studies have shown that in high modulus type fibers, the crystallites are arranged around the longitudinal axis of the fibrewith layer planes highly oriented parallel to the axis. Overall, the strength of a carbon fibredepends on the type of precursor, the processing conditions, heat treatment temperature and the presence of flaws and defects. With PAN(POLYACRYLONITRILE) based carbon fibres,the strength increases up to a maximum of 1300°C and then gradually decreases. The modulus has-been shown to increase with increasing temperature. However, similar high modulus type pitch-based fibers deform by a shear mechanism with kink bands formed at 45°to the fiber axis. Carbon fibers are very brittle. The layers in theirs are formed by strong covalent bonds. The sheet-like aggregations allow easy crack propagation. On bending, the fiber fails at very low strain.

Hybrid Composite: It is a mixing of two or more fiber materials of suitable proportions to attain desirable characteristics. In this study carbon fibers of 10-15% (by weight) is added with E-glass fiber to attain the property of fatigue resistance and also calculating the property of young's modulus forth particular hybrid composite by experimental method.

Design Concepts: In composite mono leaf spring width inconstant and thickness is decreased linearly from the center towards spring eyes. Considering the loading conditions in steel leaf spring, the mono composite leaf spring is designed according to load conditions as well as availability of space in the vehicle and geometrical considerations.

Design of Hybrid Mono Compositeleaf Spring: Hybrid composite leaf spring is designed based on steel leaf spring. For steel leaf spring, the design calculations are as follows.

- Maximum static load applied at the eye piece=3550N (Static load =14200N, No of springs=4,2F=14200/4=3550)
- Maximum load at the eye piece due to road fluctuation = 7100N
- Distance between two eye piece (span length), 2L=1000mm

Table 2: Properties of steel leaf spring

Parameters	Steel
E [Gap]	210
σ_b[N/mm^2]	562

Solution

For Steel Leaf Spring: Maximum bending stress

$$\sigma_b = 1.5WL / bt^2 \quad (1)$$

Deflection of the leaf spring

$$Y = 4WL^3/Ebt \quad (2)$$

By substituting Design stress is 799 M Pa, then,
Maximum deflection is 120 mm in equation (1)and (2)
Thickness, t =21mm and width b=15.2mm.

Butte width of the leaf must be double the thickness. Therefore the maximum width has been chosen as 45mm (nominal value).
Refer Table – 2 for properties of hybrid composite.

For hybrid composite the design calculation is as below,

Maximum bending stress

$$\sigma_b = 1.5WL / nbt^2 \quad (3)$$

Deflection of the leaf spring

$$Y = 4WL^3/Ebt^3 \quad (4)$$

By substituting design stress is 462 Mpa, Then, maximum deflection is 120 mm in equation (3)and (4) thickness at centre, t_c =28mm.

For 28mmthickness the nominal value of width is 69mm.For constant width and variable thickness, the thickness at the end(t_c) is 28mm.

☻ Thickness at the ends =

Table 3: Properties of Hybrid mono composite leaf spring

Parameters	Steel
E [GPa]	92
σ_b[MPa]	550
σ_d[MPa]	462

Modeling of Mono Composite Leaf Spring: Modeling of hybrid mono composite leaf spring is done by solid edge V19 modeling software. The model is imported to ANSYS 12. ANSYS classicism used for FEA analysis. The analysis report is given below.

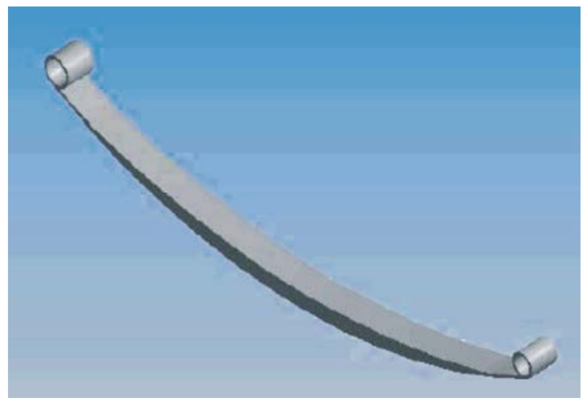

Fig. 1: 3D model of hybrid composite leaf spring

Then boundary conditions are given. In which the center of the leaf is fixed and two ends are allowed to move freely. So spring is treated as two cantilever beam

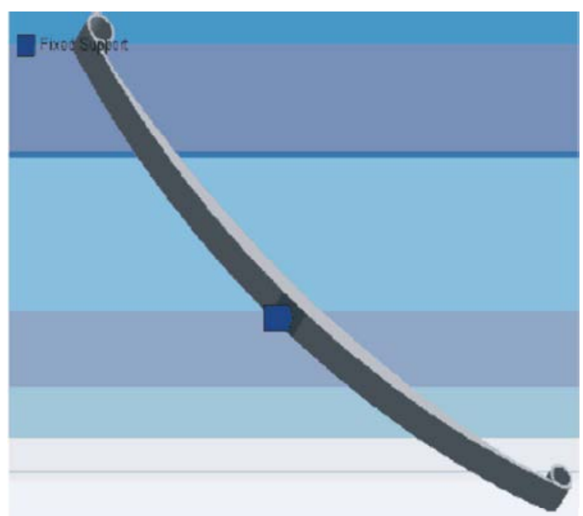

Fig. 2: Hybrid composite leaf spring fixed at centre

Results and Summary

Natural Frequency: The road irregularities usually have the maximum frequency of12Hz [10], so the leaf spring

Table 4: Frequency comparison

Frequency (HZ)	1	2	3	4	5
Steel Leaf Spring	29.6	51.8	91.9	102.4	134.3
Hybrid composite lead spring	89.34	90.95	188.90	203.15	236.89

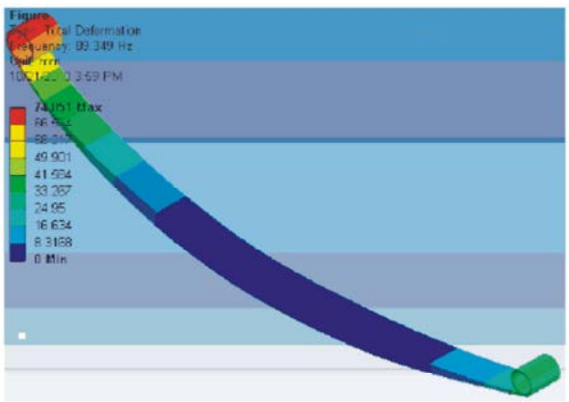

Fig. 3: Natural frequency of hybrid composite leaf spring

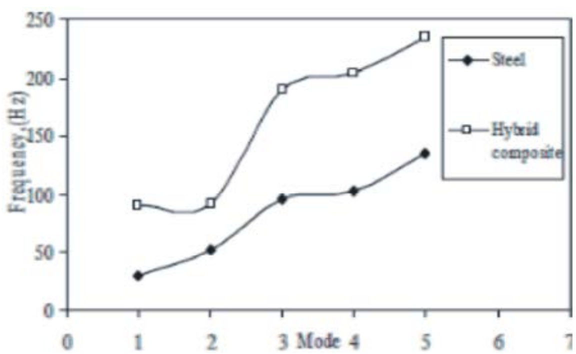

Fig. 4: Frequency analysis curve

should have a higher natural frequency to avoid resonance. The stiffness of composite leaf springs the same as the steel leaf spring but its weight is lower than the steel spring. Using ANSYS the first five natural frequencies of steel, composite and hybrid composite leaf springs are compared instable 3. In the present analysis considering Table 3,it is obvious that first natural frequency of leaf spring is nearly eight times the road frequency and it shows that resonance will not occur.

The first natural frequency analyzed by ANSYS is given in Figure 3.

Leaf spring is fixed at centre and two ends are allowed to move freely. So that the system is treated as cantilever beam. By FEA analysis, workbench is used to solve this problem. The model is created by using AUTOCAD and the same is imported to ANSYS. Then the model is meshed and mesh elements are extruded to the required width of the spring. The deflection results shown in Figure 4.

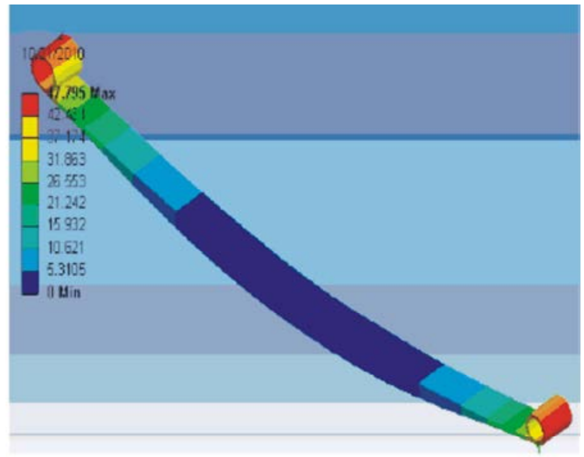

Fig. 5: Deflection of hybrid composite leaf spring

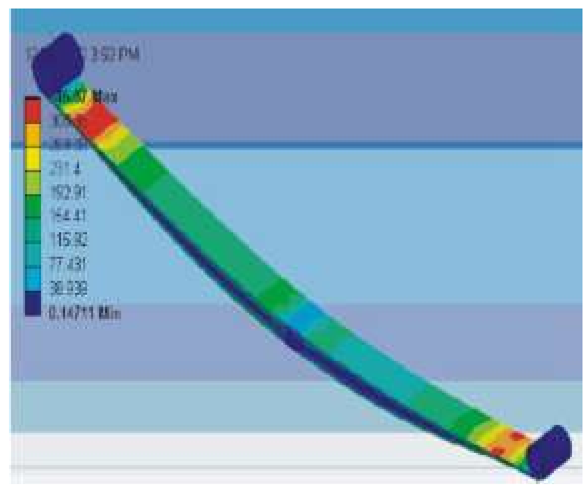

Fig. 6: Stress distribution of mono composite leaf spring

Table 5: Comparison of Stress Values

Material Orientation	Equivalent Stress	Shear Stress	Normal Stress X axis	Normal Stress Y axis
Steel	315.3	99.19	286.23	34.55
Hybrid Composite	346.87	72.411	344.10	34.37

Due to static and pumping load, spring exhibits both compressive and tensile stress. Below the neutral axis compressive stress is acting and above the neutral axis tensile load is acting. More care must be taken on the maximum value of tensile stress which is produced due to various loads.

The results obtained from figure 6 shows that the maximum stress obtained is less than the designedstress.The maximum stress value and deflection obtained from FEA analysis is with in the design value. It proves that the design is safe and the same design can be used for actual fabrication. In future work mono hybrid leaf spring is to be fabricated for the same dimensions and experimental work to be carried out to find the fatigue strength as well as inherent properties of the hybrid composite. Various stresses induced in steel and hybrid composite material is compared in the Table 5.

CONCLUSION

The Hybrid mono-composite leaf spring has-been designed and it is analyzed using the ANSYS software. Thus, the use and advantage of steel over composite material has been proved with the design and it is clearly explained through the analysis report.

Maximum stress obtained from analytical method	=	368.66 MPa
Maximum stress obtained from FEA method	=	346.87 MPa
Maximum deformation obtained from analytical method	=	47.795 mm
Maximum deformation obtained from FEAmethod	=	39.06 mm

The analyzed report proves that the chosen composite material (glass fiber + carbon fiber reinforced plastic) in this project, withstands maximum load, maximum deformation, maximum stress and which are below the designed values hence, the design is safe.

REFERENCES

1. Mahdi, E., O.M.S. Alkoles, A.M.S. Hamouda, B.B. Sahari, R. Yonus and G. Goudah, 2006. Light compositeelliptic springs for vehicle suspension. Compositestructures, 75: 24-28.
2. Rajendran, I. and S. Vijayarangan, 2001. Optimal design ofcomposite leaf spring using genetic algorithms.Computers and Structures, 79: 1121-1129.
3. Abdul Rahim, Abu Talib, Aidy Ali and NurAzida Che Lah, 2010. Developing a composite based ellipticspring for automotive applications. Matreial Anddesign, 31: 475-484.
4. ErolSancaktar and Mathieu Gratton, 1999. Design, Analysis and optimization of composite leafsprings for light vehicle applications. Compositestructures, 44: 195-204.
5. Beardmore, P., 1986. Composite structures forautomobiles. Composite structure, 5: 163-76.
6. Subramanian, C. and S. Senthilvelan, 2010. Effect ofreinforced fiber length on the joint performance ofthermoplastic leaf spring. Materials and Design, 31: 3733-3741.
7. Subramanian, C. and S. Senthilvelan, 2001. Mono compositeleaf sping for light weight cehicle-Design, EndJoint Analysis and Testing.ISSN 1392-1320. Materials science (Medziagotyra). 12(3).
8. Al-Qureshi, H.A., 2001. Automobile leaf springs fromcomposite materials. Journal of Material Processing Technology, 118: 58-61.
9. Erhard G., XXXX. Design of plastics.
10. Mahmood, M., 2003. Shokrieh, davoodRezaei. Analysisand optimization of a composite leaf spring.Composite Structures, 60: 317-325.
11. Ryan, WE., 1985. Method of making a molded fiberreinforced plastic leaf spring, US patent 4,560,525(24/12/1985).
12. Richard, D.S., J.E. Mutzner, J.F. Eilerrman, *et al*., 1990. Method of forming a composite leaf spring withfabric wear pad, US patent, 4894108 (16/1/1990).
13. Nickel, HW., 1986. Bushing construction for a fiberreinforced plastic leaf spring, US patent 4565356(21/1/1986).
14. Yu, W.J. and H.C. Kim, 1988. Double tapered FRP beam forautomotive –suspension leaf spring. Compositestructures, 9: 279-300.