Parametric Analysis Of Composite Leaf Spring

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Abstract

Reducing weight while increasing or maintaining strength of products is getting to be highly important research issue in this modern world. Composite materials are one of the material families which are attracting researchers and being solutions of such issue. The Automobile Industry has shown increase interest for replacement of steel leaf spring with that of composite leaf spring, since the composite material has high strength to weight ratio, good corrosion resistance properties. The report describes static analysis of steel leaf spring and composite leaf spring. The objective is to compare the load carrying capacity, stiffness 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 Analysis of model of leaf spring is performed using ANSYS 11.0 The result of FEA is also experimentally verified. The stress induced in the C-glass/Epoxy composite leaf spring is 64% less than that of the steel spring nearly and the deformation induced in the C-glass/Epoxy composite leaf spring is 57% less than that of the steel spring nearly. This study leaves wide scope for future investigations. It can be extended to newer composites using other reinforcing phases and the resulting experimental findings can be similarly analyzed.
Keywords: Composite, C-glass/epoxy, steel, Experimental analysis.

I. INTRODUCTION

In order to see natural resources and economize energy, weight reduction has been the main focus of automobile manufacturer in the present time. It is known that the failure nature of steel leaf springs is usually common. It is very important to reduce accidents and to replace steel leaf springs by gradually failing FRP (fiber reinforced polymer) composite material. Weight reduction can be achieved primarily by the introduction of **Better Material, Design Optimization and Better Manufacturing Processes**. The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the unsprung weight. This helps in achieving the vehicle with improved riding qualities. 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.

Compared to steel spring, the composite leaf spring is found to have 64.95% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf springs. Multi leaf springs used in the automotive vehicles normally consist of full length leaves and graduated length leaves. Moreover the composite leaf spring has lower stresses compared to steel spring. Composite materials offers opportunity for substantial weight saving. Spring are design to absorb & store energy & then release it hence strain energy of material & shape becomes major factors in designing the spring. The spring allows the movement of wheel over obstacles & then after returns the wheel to its normal position.

A. Suspension System

The automobile chassis is mounted on the axles, not direct but some form of springs. This is done to isolate the vehicle body from the road shocks, which may be in the form of bounce, pitch and roll. These tendencies give rise to an uncomfortable ride and also cause additional stress in the automobile frame body. All the part, which performs the function of isolating the automobile from the road shocks, is collectively called a suspension system. It includes the springing device used and various mountings for the same. Broadly speaking, suspension system consists of a spring and a damper. The energy of road shock causes the spring to oscillate. These oscillations are restricted to a reasonable level by the damper which is more commonly called a shock absorber.

B. Composite Materials

Composite materials are superior to all other known structure materials in specific strength and stiffness, high temperature strength, fatigue strength and other properties. The desired combination of properties can be tailored in advance and realized in the manufacture of a particular material. Moreover, the material can be shaped in this process as close as possible to the form of final products or even structural units. Composite materials are complex materials whose components differ strongly from each other in the properties, are mutually insoluble or only slightly soluble and divided by distinct boundaries.

C. MERITS OF COMPOSITE MATERIALS

- Reduced weight.

- Due to laminate structure and reduced thickness of the mono composite leaf spring, the overall weight would be less.
- Due to weight reduction, fuel consumption would be reduced.
- They have high damping capacity; hence produce less vibration and noise.
- They have good corrosion resistance.

D. DEMERITS OF COMPOSITE MATERIALS

- The leaf must span from one side of the car to the other. This can limit applications where the drive train or another part is in the way.
- Steel coils are commodity items whereas a single composite leaf spring costs more than two of them.
- Composite mono leafs allow for considerable variety in shape, thickness, and materials. They are inherently more expensive to design, particularly in performance applications.

E. APPLICATIONS OF COMPOSITE MATERIALS

- Fiber epoxy composites have been used in aircraft engine to enhance the performance of the system. The pilot's cabin door of aircrafts has also been made with fiber glass resin composites and these are now used in other transport systems
- In Railway carriages it is desirable to reduce the weight of rail car bodies as well as heavy transport vehicles, which in turn reduce power and braking requirements. It also reduces maintenance costs.
- Assembling of various parts is usually done by adhesive bonding, using resins that are catalyzed to cure at room temperature in a short time.
- An important consideration in the use of composites is light weight.

II. LITERATURE SURVEY

Investigation of composite leaf spring in the early 60’s failed to yield the production facilities because of inconsistent fatigue performance and absence of strong need for mass reduction

Erol Sancaktar, Mathieu Gratton [1] have proposed Design and manufacture of a functional composite spring for a solar powered light vehicle is described. The objective is to provide an understanding of the manufacture, use, and capabilities of composite leaf springs produced by using unidirectional E-glass impregnated by an epoxy resin for light vehicle applications where the vehicle weight is of primary concern. and conclude that The spring can be sanded down on its convex side to achieve the desired spring rate. This method proved to be very effective in reducing the spring rate.

H.A.Qureshi [2] Present the general study on design ,analysis and fabrication of composite leaf spring and conclude that composite can be used for leaf spring for light truck and meet requirement with weight saving.(2001).

Mahmood M. Shokrieh, Davood Rezaei [3] used A four-leaf steel spring used in the rear suspension system of light vehicles is analyzed using ANSYS V5.4 software.and finally showing stresses and deflections verified the existing analytical and experimental solutions. Using the results of the steel leaf spring, a composite one made from fiberglass with epoxy resin is designed and optimized using ANSYS.(2003).

M.A. Osipenko, R.N. Rudakov [4] Take the leaves have the same widths and different lengths (the lengths decrease upwards).and Each leaf has one end clamped and the other free.for that they gave loading is applied (upwards) to the lower leaf. and finding the densities of the forces of interaction between the leaves and investigation of the interaction of spring leaves under joint bending allows one to understand the bending of two straight uniform leaves in full.(2003)

Gulur Siddaramanna Shiva Shankar, Sambagam Vijayarangan [5] have present a low cost fabrication of complete mono composite leaf spring and mono composite leaf spring with bonded end joints. Also, general study on the analysis and design. A single leaf with variable thickness and width for constant cross sectional area of unidirectional glass fiber reinforced plastic with similar mechanical and geometrical properties to the multi leaf spring, was designed, fabricated and tested. Computer algorithm using C-language has been used for the design of constant cross-section leaf spring. and conclude that a spring width decreases hyperbolically and thickness increases linearly from the spring eyes towards the axle seat. The finite element results using ANSYS software showing stresses and deflections were verified with analytical and experimental results. The design constraints were stresses and displacement. Compared to the 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.(2006)

J.P. Hou, J.Y. Cherruault, I. Nairne, R.M. Mayer[6] present the design evolution process of a composite leaf spring for freight rail applications. Three designs of eye-end attachment for composite leaf springs are described. The material used is glass fiber reinforced polyester. Static testing and finite element analysis have been carried out to obtain the characteristics of the spring. Load–deflection curves and strain measurement as a function of load for the three designs tested have been plotted for comparison with FEA predicted values .and conclude Three eye-end designs of a double GRP leaf suspension have been evaluated by finite element analysis and static and fatigue testing. FEA and static test results show that the stress concentration at the tip of the fibers coming back along the leaf body.

M. M. Patunkar, D. R. Dolas [7] Present modeling and analysis of composite mono leaf spring (GFRP) and compare its results. Modeling is done using Pro-E (Wild Fire) 5.0 and Analysis is carried out by using ANSYS 10.0 software for better understanding and conclude that Under the same static load conditions deflection and stresses of steel leaf spring and composite leaf spring are found with the great difference. Deflection of Composite leaf spring is less as compared to steel leaf spring with the same loading condition. Conventional steel leaf spring was found to weigh 23Kg. whereas E-Glass/Epoxy mono leaf spring weighs only 3.59 Kg. Indicating reduction in weight by 84.40% same level of performance.(2011).

B.Vijaya Lakshmi, Satyanarayana [8] have compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. The design constraints are stresses and deflections. The dimensions of an existing conventional steel leaf spring of a Heavy commercial vehicle are taken Same dimensions of conventional leaf spring are used to fabricatea composite multi leaf spring using E-GLASS/EPOXY, C- GLASS/EPOXY, S- GLASS/EPOXY unidirectional laminates. Pro/Engineer software is used for modeling and COSMOS is used for analysis. Static & Dynamic analysis of Leaf spring is performed using COSMOS.

Shishay Amare Gebremeskel [9] reducing weight of vehicles and increasing or maintaining the strength of their spare parts is considered. As leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, a single E-glass/Epoxy leaf spring is designed and simulated following the design rules of the composite materials considering static loading only. shown that the resulting design and simulation stresses are much below the strength properties of the material, satisfying the maximum stress failure criterion. The designed composite leaf spring has also achieved its acceptable fatigue life.

Ghodake A. P., Patil K.N. [10] study the material selected was glass fiber reinforced plastic (GFRP) and the polyester resin (NETPOL 1011) is used against conventional steel. A spring with constant width and thickness was fabricated by hand lay-up technique which was very simple and economical. The numerical analysis is carried via finite element analysis using ANSYS software. Stresses, deflection and strain energy results for both steel and composite leaf spring material were obtained and conclude that the composite spring has maximum strain energy than steel leaf spring and weight of composite spring was nearly reduced up to 85% compared with steel material.

III. DESIGN AND MODELING

F. Material Selection

Materials constitute nearly 60%-70% of the vehicle cost and contribute to the quality and the performance of the vehicle. Even a small amount in weight reduction of the vehicle, may have a wider economic impact. Composite materials are proved as suitable substitutes for steel in connection with weight reduction of the vehicle. Hence, the composite materials have been selected for leaf spring design.

1) Fiber Selection

The commonly used fibers are carbon, glass, etc. Among these, the glass fiber has been selected based on the cost factor and strength. The types of glass fibers are C-glass, S-glass and E-glass. The C-glass fiber is designed to give improved surface finish. S-glass fiber is design to give very high modular, which is used particularly in aeronautic industries. The E-glass fiber is a high quality glass, which is used as standard reinforcement fiber for all the present systems well complying with mechanical property requirements. Thus, E-glass fiber was found appropriate for this application.

Vertical vibrations and impacts are buffered by variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. The material used directly affects the quantity of storable energy in the leaf spring. The specific strain energy can be written as Eq. (1).

$$S = (1/2) \times ((\sigma_t^2)/(\rho E)) \qquad \text{-----------(1)}$$

Where, σ_t is the allowable stress, (N/mm²) E is the modulus of elasticity and(N/mm²) ρ is the density.(Kg/m³)

Table. 1: Strain Energy Stored By Material (Kj/Kg)

Sr. No	Material	Strain Energy Stored By Material (KJ/Kg)
1	steel (EN47)	0.3285
2	E-glass/Epoxy	4.5814
3	C-glass/Epoxy	18.76
4	S-glass/Epoxy	32.77

Although S-2 fibers have better mechanical properties than C fibers, but the cost of C fibers is much lower than S-2 fibers. As the energy storage capacity of C-glass/epoxy is much higher than E-glass/epoxy there for it is the best material for the application selected. Also from the Eq. (1) the material with maximum strength and minimum modulus of elasticity is the most suitable material for the leaf spring application.

2) Resin Selection

In a FRP leaf spring , the inter laminar shear strengths is controlled by the matrix system used . Since these are reinforcement fibers in the thickness direction, fiber do not influence inter laminar shear strength. Therefore, the matrix system should have good inter laminar shear strength characteristics compatibility to the selected reinforcement fiber. Many thermo set resins such as polyester, vinyl ester, epoxy resin are being used for fiber reinforcement plastics (FRP) fabrication . Among these resin systems,

epoxies show better inter laminar shear strength and good mechanical properties. Hence, epoxies are found to be the best resins that would suit this application. different grades of epoxy resins and hardener combinations are classifieds based on the mechanical properties which in combination with hardener 758 cures into hard resin.
It is characterized by

- Good mechanical and electrical properties.
- Faster curing at room temperature.
- Good chemical resistance properties.

Matrix materials or resins in case of polymer matrix composites can be classified according to their chemical base i.e. thermoplastic or thermo sets. Thermoplastics have excellent toughness, resilience and corrosion resistance but have fundamental disadvantage compared to thermosetting resins, in that they have to be molded at elevated temperature.
Thermosetting plastics or thermo sets are formed with a network molecular structure of primary covalent bonds. Some thermo sets are cross-linked by heat or a combination of heat and pressure. Others may be cross-linked by chemical reaction, which occurs at room temperature.

At present, epoxy resins are widely used in various engineering and structural applications such as aircraft, aerospace engineering, sporting goods, automotive, and military aircrafts industries. In order to improve their processing and product performances and to reduce cost, various fillers are introduced into the resins during processing. Epoxy resins are the most commonly used thermo sets plastic in polymer matrix composites. Hence from the above listed advantages of epoxy resin it has been selected for the study.

G. Design Selection

The leaf spring behaves like a simply supported beam and the flexural analysis is done considering it as a simply supported beam. The simply supported beam is subjected to both bending stress and transverse shear stress. Flexural rigidity is an important parameter in the leaf spring design and test out to increase from two ends to the center.

Constant Thickness, Varying Width Design: In this design the thickness is kept constant over the entire length of the leaf spring while the width varies from a minimum at the two ends to a maximum at the center.

Constant Width, Varying Thickness Design: In this design the width is kept constant over the entire length of the leaf spring while the thickness varies from a minimum at the two ends to a maximum at the center.

Constant Cross-Selection Design: In this design both thickness and width are varied throughout the leaf spring such that the cross-section area remains constant along the length of the leaf spring.
Out of the above mentioned design concepts, the constant cross-section design method is selected due to the following reasons:-

- Due to its capability for mass production and accommodation of continuous reinforcement of fibers.
- Since the cross-section area is constant throughout the leaf spring, same quantity of reinforcement fiber and resin can be fed continuously during manufacture.
- Also this is quite suitable for filament winding process.

1) Selection of Manufacturing Process
Apart from the selection of material and design procedure, the selection of manufacturing process also determines the quality and cost of the product. Hence, the composite leaf spring manufacturing process should fulfill the following criteria.

- The process should be amenable to mass production.
- The process should be capable of producing continuous reinforcement fiber.

Based on above requirements, filament-winding techniques are selected. In filament winding process, continuous fiber under controlled tension are drawn from spools mounted on creel stands wetted with the resin by passing the fibers through a resin bath and wound onto the rotating mould. After achieving the desired thickness, the process is stopped and the mould is removed from the machine and kept for curing. This process doesn't involve huge investment.

A number of processes have been developed to produce and shape the fiber reinforced composites. Variations are based primarily on the orientation of the fibers, the length of continuous filaments & the property of the final product. Each seeks to embed the fibers in a selected matrix with the proper alignment & spacing necessary to produce the desired properties. Discontinuous fibers can be combined with a matrix to produce either a random or preferred orientation. Continuous fibers are normally aligned in a unidirectional fashion in rods or tapes, woven into fabric layers, wound around a mandrel, or woven into a three dimensional shape.
2) Hand Lay-up Technique
Normally the work is carried out in a female mould – a GRP mould with a polished gel coat surface on the inside. Having acquired and set up the mould at a convenient working height in the workshop, the following procedure should be adopted:

- Wash the mould carefully with warm water and soft soap to remove any old PVC release agent, dust, grease, finger marks, etc.
- Dry the mould thoroughly.
- Check the mould surface for chips or blemishes. These should be repaired by filling with polyester filler and cutting back with wet/dry paper. The odd small chip can be temporarily repaired by filling with filler material.
- If the mould surface is in good condition the mould release wax is now applied, with a circular motion, using a small piece of cloth. Three coats of wax are sufficient for a mould surface which has been previously 'broken in' but a new mould surface will require at least six applications. Each application is polished up to a high shine with a large piece of cheese

cloth, after being left to harden for 15-20 minutes. Care must be taken to remove all streaks of wax. Be sure that the wax is polished and not removed by aggressive buffing. Failure to take care at this stage can result in stick up. Check application with manufacturer’s instructions.

- The glass fiber was cut to desired length, so that they can be deposited on mold layer- by layer during fabrication of composite leaf spring.
- Prepare the solution of resin & Place the first layer of glass fiber chopped mat on mould followed by epoxy resin solution over material.
- Wait for 5-10 min. Repeat the procedure till the desired thickness was obtained. The duration of the process may take up to 25- 30 min. And finally remove the leaf spring from mould.

IV. EXPERIMENTAL ANALYSIS

Electronic ranges of Universal Testing Machines are fast, accurate, & simple to operate. In these machines load and displacement are displayed on the digital display system in their respective engineering units. It is supported by windows based software which can store, retrieve readings as and when required.

The machine is capable of performing the following tests:-

- Tension
- Compression
- Transverse
- Bending
- Shear
- Hardness

Table. 2: Technical Specification of Universal Testing Machine

Sr. No.	Technical specifications	Requirement
1	Capacity	Up to 40T
2	Minimum test Speed	0.01 mm/min
3	Maximum test Speed	500 mm /min
4	Width	Preferably in the range of 1000-1200 mm
5	Depth	Preferably in the range of 500-600 mm
6	Height	Preferably in the range of 1600-2000 mm
7	Total Crosshead Travel	Preferably in the range of 1200-1400 mm
8	Total Vertical Test Space	Preferably in the range of 1200 mm-1400Mm
9	Diameter of roller	30 mm
10	Length of Roller	170 mm
11	Maximum span between the Roller	600 mm

The deflection and stress of both the spring for comparative study is taken on the Universal Testing Machine (UTM). In the experimental analysis the comparative testing of mono composite leaf spring and the steel leaf spring are taken.

H. Procedure for Testing

- The spring to be tested is examined for any defects like cracks, surface finishing, etc.
- Move the plunger up to desired height so that we can fix the fixture and leaf spring for test.
- Fix the position of fixture. On the fixture place the specimen.
- The load is applied at the centre of spring, the vertical deflection of the spring centre is recorded at desired interval.

V. RESULT AND DISCUSSION

I. Bending stress

It can be observed from the comparison that the bending stress induced in the C-Glass/Epoxy composite leaf spring is **64%** less than the conventional steel leaf spring for the same load carrying capacity.

Table. 3: Comparison Of FEA And Experimental Result

Sr. No	load (W) (N)	FEA Result Bending stress (σ) (N/mm²)		Experimental Result Bending stress (σ) (N/mm²)	
		Steel Spring	Composite Spring	Steel Spring	Composite Spring

1	4500	47.69	33.33	47.22	33.52
2	5000	137.45	52.56	136.66	52.88
3	5500	223.1	79.49	222.77	80.27

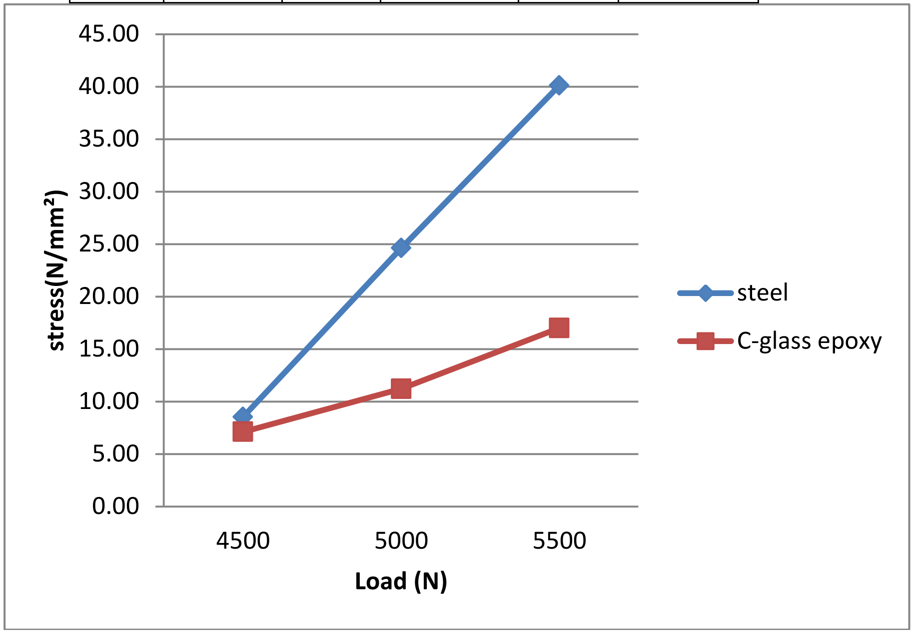

Fig. 1: load vs stress

VI. CONCLUSION

The conclusion of the work is to minimize stress and deformation in C-Glass/Epoxy composite leaf spring compared to steel leaf spring for automobile suspension system. This is done to achieve the following-

It can be observed from the comparison that the bending stress induced in the C-Glass/Epoxy composite leaf spring is 64% less than the conventional steel leaf spring for the same load carrying capacity.

- This design helps in the replacement of conventional steel leaf springs with composite mono-leaf spring with better ride quality.
- To achieve weight reduction in the suspension system by replacing steel leaf spring with mono composite leaf spring

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