

## Exploration on Fabrication and Analysis of suitability composite leaf spring on vehicles and their advantages

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**Abstract:** The subject gives a brief look on the suitability of composite leaf spring on vehicles and their advantages. Efforts have been made to reduce the cost of composite leaf spring to that of steel leaf spring. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very replacement material for conventional steel. Material and manufacturing process are selected upon on the cost and strength factor. The design method is selected on the basis of mass production. From the comparative study, it is seen that the composite leaf spring are higher and more economical than conventional leaf spring.

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**Keywords:** Fabrication, Leaf Spring, Manufacturing and Process

### 1. Introduction

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers in the present scenario. 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 automobiles as it accounts for 10% - 20% of the unsprung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. The introduction of composite materials was made it possible to reduce the weight of leaf spring without any reduction on load carrying capacity and stiffness. Since, the composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel, multi-leaf steel springs are being replaced by mono-leaf composite springs. The composite material offer opportunities for substantial weight saving but not always are cost-effective over their steel counterparts. 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. Emphasis of vehicles weight reduction in 1978 justified taking a new look at composite springs. Studies are made to demonstrate viability and potential of FRP in automotive structural application.

The development of a litelflex suspension leaf spring is first achieved. Based on consideration of

chipping resistance base part resistance and fatigue resistance, a carbon glass fiber hybrid laminated spring is constructed. A general discussion on analysis and design of constant width, variable thickness, and composite leaf spring is presented. The fundamental characteristics of the double tapered FRP beam are evaluated for leaf spring application. Recent developments have been achieved in the field of materials improvement and quality assured for composite leaf springs based on microstructure mechanism. All these literature report 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. Material properties and design of composite structures are reported in many literatures. Very little information is available in connection with finite element analysis of leaf spring in the literature, than too in 2D analysis of leaf spring. At the same time, the literature available regarding experimental stress analysis more. The experimental procedures are described in national and international standards. Recent emphasis on mass reduction and developments in materials synthesis and processing technology has led to proven production worthy vehicle equipment.

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.

The commonly used fibers are carbon, glass, kevlar, 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.

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, azoxy 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, epoxide is found to be the best resins that would suit this application. Different grades of epoxy resins and hardener combinations are classified, based on the mechanical properties. Among these grades, the grade of epoxy resin selected is Dobeckot 520 F and the grade of hardener used for this application is 758. Dobeckot 520 F is a solvent less epoxy resin. Which in combination with hardener 758 cures into hard resin? Hardener 758 is a low viscosity polyamine. Dobeckot 520 F, hardener 758 combination is characterized by (a) Good mechanical and electrical properties (b) Faster curing at room temperature and (c) Good chemical resistance properties.

## 2. Material and Methods

**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. (a) Due to its capability for mass production and accommodation of continuous reinforcement of fibers (b) Since the cross-section area is constant throughout the leaf spring, same quantity of reinforcement fibre and resin can be fed continuously during manufacture and (c) Also this is quite suitable for filament winding process. A computer algorithm using C language has been developed for the design of constant cross-section leaf spring. In constant cross-section on design both the thickness and width are varied through to the leaf spring such that the cross-section area remains constants. Considering the bearing strength of the steel plate, the calculated thickness of the leaf at the bolted ends (tc) is 7.5 mm. Based on the leaf interchangeability in mounting the rear axle, the width at the center (bm) is chosen as 30 mm and corresponding thickness (tm) 31 mm. Stress and deflections are calculated from the theory of bending. The output of computer algorithm is the dimensions (breadth and thickness) of leaf spring at various distances from the center. The dimensional details can be utilized in developing models for finite element analysis and mould making process.

### 2.1 Three Dimensional finite Element Analyses

The composite leaf spring is analyzed for static strength and deflection using 3D finite element analysis. The general purpose finite element analysis software ANSYS versin5.5 is used for the present study. Using the advantage of symmetry in geometry and loading, only one-half of the leaf spring is modeled analyzed. The three dimensional structure of the leaf spring is divided into a number eight-nodded 3D brick elements. in order to get accurate results, more number of elements are to be created. Hence, an aspect ratio of three is maintained in the finite element model. The variation of bending stress and displacement values are predicted. The composite leaf spring from undeformed shape, it is observed from the results that the composite leaf spring functions equally as the conventional leaf spring under similar loading conditions.

### 2.2 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. 1) The process should be amenable to mass production and 2) 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.

### 2.3 Fabrication

In this section the details of mould fabrication, filament winding machine, winding setup, resin preparation, winding process and metallic eye are discussed.

#### Mould Fabrication

The mould used for the fabrication of FRP leaf spring should satisfy the following requirements. (a) The cavity of the mould should resemble the actual leaf spring shape and dimension (b) It should have a continuous positive surface of resolution and (c) It should be designed such that it can be rotated about an axis of revolution. The mould is designed as per the design of the constant cross-section leaf spring and above the requirements. After deciding the dimensions of the mould, it is manufactured using wood as the pattern material. Adding small wooden pieces along its boundaries create the composite leaf spring.

### 2.4 Filament Winding Machine

The mould that is used for the manufacture of composite leaf spring has an outer dia. of one meter. The mould after mounting on the machine has to be rotated as the fibre is wound on it. Hence a machine, which has the swing over dia. of one meter, has to be used. This led to the selection of the horizontal-boring machine which has an adjustable swing over die. An attachment is also fabricated for mounting the mould on to the spindle head of the boring machine.

### 2.5 Winding Setup

The actual winding of the leaf spring involves the operation of the winding machine, after attaching the resin bath and mould. Before the process is started, the epoxy resin and hardener combination has to be placed in the resin bath. The resin bath is an important unit of the winding setup. It provides the necessary matrix impregnation to fibres before they are wound over the mould surface. The resin bath should accomplish the following requirements. (a) It should wet the fibre roving uniformly with a controlled amount of resin (b) The capacity of the resin bath should be sure that all the resin poured should be utilized completely (c) The resin must be poured at constant temperature to maintain a constant viscosity and (d) It should avoid fibre breakage during impregnation. The resin bath consists of a number of rollers, which are placed to guide the fibres. The fibres from the creel stand are allowed to pass through the rollers that are placed well inside the resin bath. This enables the fibres to get completely soaked in the resin. The soaked fibre is then allowed to pass through two rollers, which are rotating in opposite directions. By this method the

amount of resin in the fiber is found. The filament winding setup is shown here. The mould is first mounted on the filament winding using the fabricated attachment and then it is rotated at a speed of 15 rpm.

#### Resin Preparation

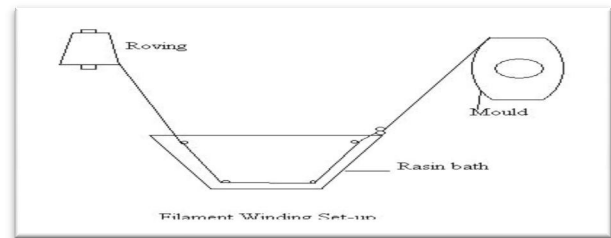
The selected epoxy resin is Dobeckot 520 F with hardener 758. For every 100 parts by weight of Dobeckot 520 F, 10-12 parts by weight of hardener 758 is mixed well at a temperature of 20°C- 40°C and used within 30-40 min, since the gel time of epoxy resin is 30-40 min.

#### Winding Process

After the preparation of the resin, the resin is poured into the resin bath and the fiber placed in the creel stand is allowed to pass through rollers in the resin bath. The soaked fibre is then allowed to pass over the mould. The process is continued till the desired thickness is achieved.

#### Metallic Eye

Since it is difficult to fabricate a leaf spring with the eye portion by filament winding process, a separate metallic eye is fabricated and then fixed to the leaf spring.



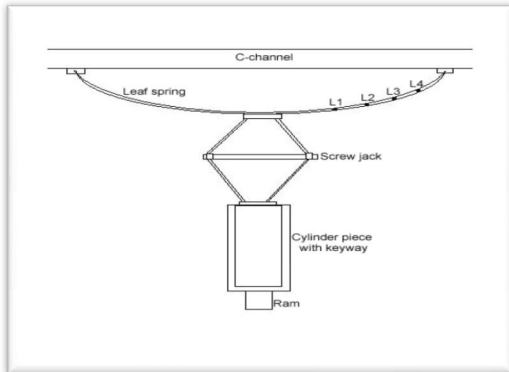
## 3. Results

In this section the machine details and testing details of composite leaf spring are discussed. The static and fatigue tests are also covered. The main problem faced in using a standard material testing machine for testing a leaf spring is the displacement. The standard machines are designed for a displacement in the order of microns. But the leaf spring testing machine must permit displacements in the order of centimeters. The machine must be capable of exerting heavy loads in the range of a few tones. The machine must be equipped with a suitable fixture, which will simulate the actual mounting of the leaf spring in the automobile. This led to the need of a servo-hydraulic testing machine for the testing of leaf springs. Hence, a hydraulic-testing machine for testing of leaf springs has been designed and fabricated. The special fixture arrangement for leaf spring testing is shown below.

### 3.1 Composite Leaf Spring Testing

The leaf springs are tested following standard procedures recommended by SAE. The spring to be tested is examined for any defects like cracks, surface abnormality, etc. and the surface where the strain

gauges are to be fixed is cleaned free from dust, rust and any greases. Then, strain gauges are fixed to the prepared surface by using a cyano-acrylate adhesive.



### Static Test

The spring is loaded from zero to the prescribed maximum deflection and back to zero. The applied load is measured near the center clamp location. The vertical deflection of the spring center is also measured. The test readings are recorded at four locations where the strain gauges are fixed in actual experimental conditions. The variations of bending stress with load at location 1 to location 4 are shown in the figure. The graphs are drawn when applying the load and releasing the load.

### Fatigue Test

A fatigue analysis is carried out with the help of hydraulic-fatigue testing machine. The designed and fabricated composite leaf spring is mounted on testing machine and the limit switches are fixed at a span of 50 mm in the vertical direction. This is the amplitude of loading cycle, which is considerably high amplitude. The frequency of one cycle is 66 mHz, which is considered to be very low. This leads to high amplitude low frequency fatigue test. During the test the value of strain at location 1 is recorded. The maximum and minimum stress values obtained at the first cycle of the composite leaf spring are 299 MPa and 202 MPa respectively. As the number of cycles goes on increasing, the fluctuation in the stress are continuing to a certain level then settling takes place. Under this condition, the maximum and minimum operating stress values are found to be 310 MPa and 208 MPa, respectively. Since, the fatigue (tensile) strength of the composite material is considered as 900 MPa, the stress level obtained from operating stress is 0.33, which is very low and safe. Due to high amplitude and low frequency fatigue analysis, the experimental analysis doesn't provide final results in the short period. The test is conducted for 100 to complete 25,000 cycles. The variations in stress level are reduced to very low level after 25,000 cycles. It is

observed from the fatigue test that there is only a negligible reduction in spring rate (1.5%) and no crack initiation in the spring after 25,000 cycles of fatigue loading. Hence there is necessity to go for analytical model for finding the remaining number of cycles of fatigue.

### Comparison with steel leaf spring

The objective of this study is to evaluate the applicability of a composite leaf spring in automobiles by considering cost-effectiveness and strength. The comparison between multi-leaf spring and mono-leaf composite spring is made for the same requirements and loading conditions. The comparison is based on four major aspects such as weight, riding comfort, cost and strength. Comparison of weight. The total weight of composite leaf spring is 4 Kg including the metal eye weight of 1 Kg. The weight of a conventional steel spring assembly is around 15 Kg. So, around 70% of weight reduction is achieved. Thus the objective of reducing the unsprung mass is achieved to a larger extent.

### Comparison based on rigidity qualities

The weight reduction of unsprung mass of an automobile will improve the riding quality. The suspension leaf contributes 10% - 20% of the unsprung mass. The weight of the composite leaf spring is 3.75 times less than steel leaf spring. Hence the riding comfort of an automobile is increased due to the replacement of the steel leaf spring by composite leaf spring. No one to the best of knowledge has worked but qualitatively on how much improvement in mileage/lit of passenger vehicle occurs and how much riding comfort improves. Only qualitative information is available on riding comfort of vehicle with respect to its unsprung mass. Steel spring is a multi-leaf spring and its inter-leaf fabrication reduces its riding quality. But composite leaf spring is a mono-leaf spring and more conducive to riding qualities. Since, the composite leaf spring is able to with stand the static load as well as the fatigue load, it is concluded that there is no objection from strength point of view also, in the process of replacing conventional leaf spring by composite leaf spring. To establish the consistency of test results, extensive trail on a large scale has to carry out. This requires large time and infrastructure, which are beyond the scope of the present study. Since, the composite spring is designed for same stiffness as that of steel spring, both the springs are considered to be almost equal in car stability. The major disadvantage of composite leaf springs is cost and resistance. In this study, the cost factor has been proved to be ineffective. However the matrix material is likely to chip off when it is subjected to poor road environment (ie; if some stone hit the composite leaf spring then it may produce chipping), which may sometimes break the fibres in

the lower portion of the spring. This may result in a loss of capability to share flexural stiffness. But this depends on the condition of the road. In normal road condition, this type of problems will not occur.

#### 4. Conclusion

The composite leaf spring is designed according to constant cross-section area method. The 3-D model of the composite leaf spring is analyzed using finite element analysis. Static test has been conducted to predict the stress and displacement at different locations for various load value. The results of the FEM analysis are verified with the test results. A comparative study has been made between composite and steel leaf springs with respect to weight, riding quality, cost and strength. From the study it is seen that the composite leaf spring are lighter and more economical than that of conventional steel leaf springs for similar performance. Hence, the composite leaf springs are the suitable replacements to the conventional leaf springs.

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