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# Weight and Material Optimization of Mono Leaf Spring for Light Weight Vehicle

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**Abstract:** Of late, Fiber glass composite mono leaf spring has become the 'in thing' in spring design for light weight vehicles. Better strength, stiffness & light weight are the plus points of such mono leaf springs. It has higher strength to weight ratio than multi-leaf springs. In comparison with conventional leaf springs, composite mono leaf spring much lowers stress, higher nature frequency & lower spring weight.

**Keywords:** Mono Leaf Spring, GERP, Light Weight Vehicle, FEA

## 1. Introduction

Failure of leaf spring in vehicles is one of the major causes of accidents. Single composite leaf springs have the lowest failure rate, which can be considerably reduce the number of accidents. It brings down the overall weight of the vehicles without affecting the load carrying capacity (in the order of 10% to 20%). The composite material used in the structure of mono-leaf spring has more elastic strain energy storage capacity & high strength to weight ratio than that of used in multi-leaf springs.

The leaf spring is designed to absorb all vertical vibrations & impacts caused by the irregular layout of the road surfaces by virtue of the vibrations in the spring deflections so that the strain energy inherent the spring body is released slowly. So a highly effective suspension system is created by the increased energy storage capacity if the composite mono-leaf spring. Studies have shown that a material with maximum strength & minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring; & composites are ideal examples with all these properties.

This paper aims at replacing multi-leaf steel spring with a composite mono-leaf spring of glass/Epoxy composites.

## 2. Lay up Selection

The amount of elastic energy that can be stored by a leaf spring varies directly with the square of maximum allowable stress and inversely with the modulus of elasticity both in the longitudinal direction. Composite materials like the E-Glass/Epoxy in the direction of fibers have stable characteristics for storing strain energy. So, the layup is selected to be unidirectional along the longitudinal direction of the spring. The unidirectional layup may weaken the spring at the mechanical joint area and require strengthening the spring in this region [1]. The some dimensions for both steel leaf spring and composite leaf springs are considered to be the same. The primary objective is to compare their load carrying capacity, stiffness and weight savings of composite leaf spring. Finally, fatigue life of steel and composite leaf spring is also predicted using life data [1]. The conventional steel leaf spring is tested for static load condition and results are compared with a virtual model of composite material leaf spring.

Results of Composite Leaf Spring are compared on the basis of analysis reports produced by ANSYS software. The material used for conventional steel leaf spring is 55Si2Mn90 and for composite leaf spring E-Glass/Epoxy material is used [2].

## 3. Material for Leaf Spring

High damping capacity of composite materials suitable for automotive applications in which noise, vibration, and hardness is a critical issue for passenger comfort.

Selection of the suitable material is a key factor because of overall properties for the composite spring depends upon the material used for the spring. Fiber Reinforced Composites

(FRP) is materials consisting of fibers of high strength and modulus embedded in or bonded to resins with distinct interfaces between them. In this form, both fibers and resins retain their physical and chemical identities yet they produce combination of properties that cannot be achieved with either of the constituents separately. In general, fiber is the principal load carrying members, while the surrounding resins keep them in desired location and orientation.

The material for conventional steel leaf spring is 55Si2Mn90. Material selected for mono composite spring is E- glass/Epoxy i.e. Eglass-60%, Epoxy resin-40%. A mono-leaf E-glass–epoxy has been used to replace a three-leaf steel spring with nearly an 80% weight savings [2].

## 4. Design of Mono Leaf Spring

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. The constant cross-section design method is selected due to the following reasons:

Owing its capability for mass production of continuous reinforcement of fibers, the cross-section area is constant throughout the leaf spring, same quantity of reinforcement fiber and resin can be fed continuously during manufacture [3]. The joint consists of a steel eye that can be bolted or pinned to the spring. Because of drilling, a region of stress concentration will exist around the holes in this type of attachment. Simplicity and low cost are the advantageous of this attachment.

***Table 1.*** *Actual Parameter of Conventional Steel Leaf Spring.*

| Sr. No | Parameter | Value |
|---|---|---|
| 1 | Material selected | Steel–55Si2Mn90 |
| 2 | Tensile strength ($N/mm^2$) | 1962 |
| 3 | Yield strength ($N/mm^2$) | 1470 |
| 4 | Young's modulus E ($N/mm^2$) | 2.1e5 |
| 5 | Total Length (mm) | 850 |
| 6 | Spring width (mm) | 60 |
| 7 | Spring weight (Kg) | 22 |
| 8 | Thickness of leaf (mm) | 8 |
| 9 | Maximum load given on spring (N) | 4000 |

***Table 2.*** *Design Parameter for Composite Mono Leaf Spring.*

| Sr. No | Parameter | 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 µxy) | 0.217 |
| 10 | Poisson ratio along YZ- direction µyz) | 0.366 |
| 11 | Poisson ratio along ZX- direction µzx) | 0.217 |
| 12 | Mass density of the material (ρ), kg/mm3 | 2.6e-6 |
| 13 | Flexural modulus of the material, MPa | 40000 |
| 14 | Flexural strength of the material, MPa | 1200 |

## 5. Manufacturing / Fabrication Process

The constant cross-section design is selected due to its capability for mass production & to accommodate continuous reinforcement of fibers and also it is quite suitable for hand lay-up technique. Many techniques can be suggested for the fabrication of composite leaf spring from unidirectional GERP. Composite leaf spring was fabricated using wet filament winding technique [4]. In the present work, the hand lay-up process was employed.

The templates (mould die) were made from wood and plywood according to the desired profile obtained from the computer algorithm. The glass fibers were cut to the desired lengths, so that they can be deposited on the template layer by layer during fabrication. In the conventional hand lay-up technique, a releasing agent (gel/wax) was applied uniformly to the mould which had good surface finish. This is followed by the uniform application of epoxy resin over glass fiber. Another layer was made and epoxy resin was applied and a roller was used to remove all the trapped air. This process continued till the required dimensions were obtained. Care had to be taken during the individual lay-up of the layers to eliminate the fiber distortion, which could result in lowering the strength and rigidity of the spring as a whole. The duration of the process may take up to 30 min. The mould was allowed to cure for about 4–5 days at room temperature. Mono composite leaf springs with and without eye ends were fabricated by using the technique [5].

## 6. Experimental Setups

The steel and composite leaf springs were tested by using leaf spring test rig. The experimental set up is shown in Figs. 1, 2 and 3. The leaf springs were tested following standard procedures recommended by SAE. The spring to be tested has examined for any defects like cracks, surface abnormalities, etc. The spring was loaded from zero to the prescribed maximum deflection and back to zero.

The load was applied at the centre of spring; the vertical deflection of the spring centre was recorded in the load interval of 50 N.

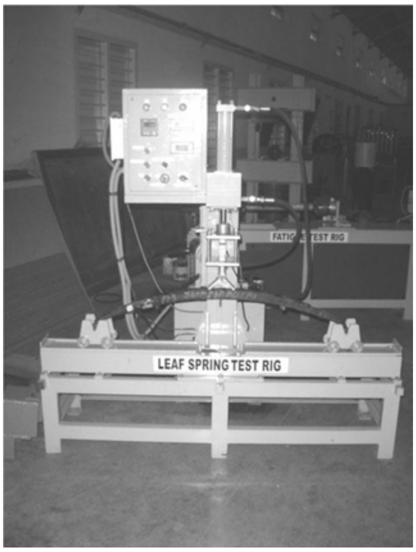


***Figure 1.*** *Static load test for steel leaf spring.*


***Figure 2.*** *Static load test for composite mono leaf spring.*

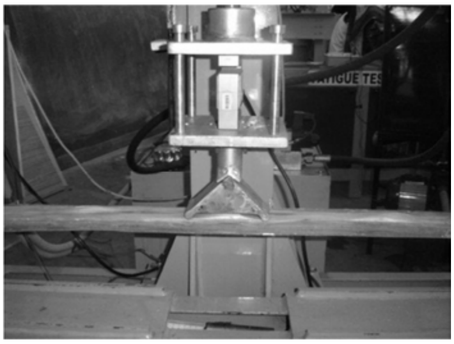

***Figure 3.*** *Static load test for maximum deflection.*

## 7. Finite Element Analysis

To design the composite spring, a stress analysis was performed using the finite element method done using ANSYS software & modeling was done on software Pro-E. Also, analysis was carried out for composite leaf spring with end joints for E-glass / Epoxy. The maximum shear stresses along the adhesive layer were measured and represent the FEA results of composite mono leaf spring [6].

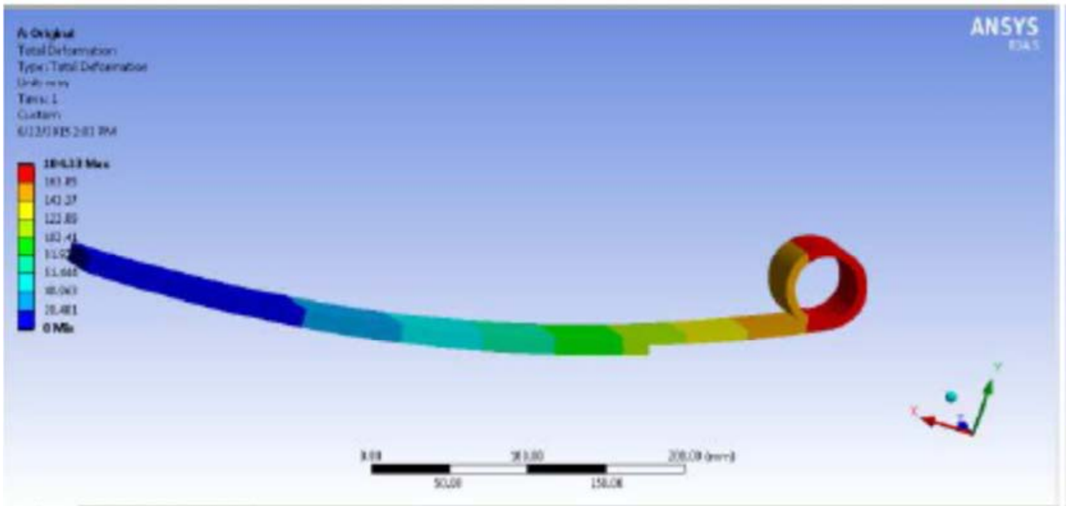


***Figure 4.*** *Displacement pattern for steel leaf spring.*

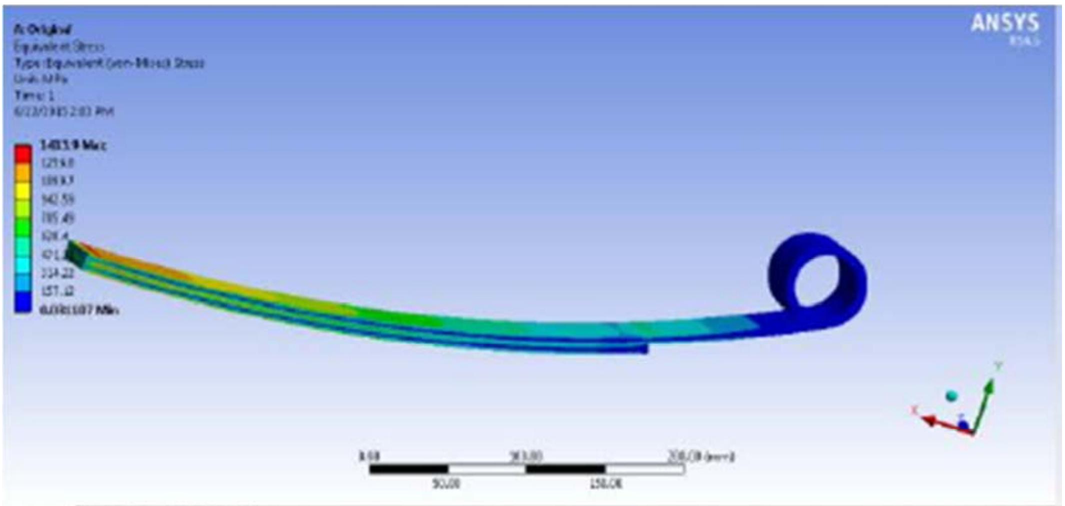


***Figure 5.*** *Stress distribution for steel leaf spring.*

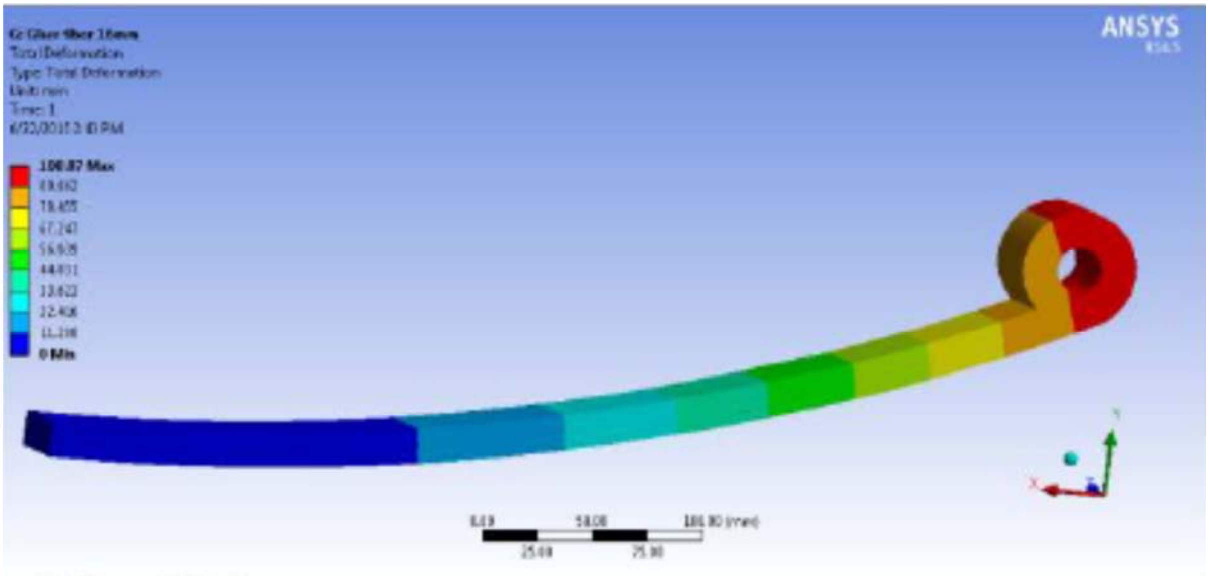


***Figure 6.*** *Displacement pattern for Glass/Epoxy composite leaf Spring.*

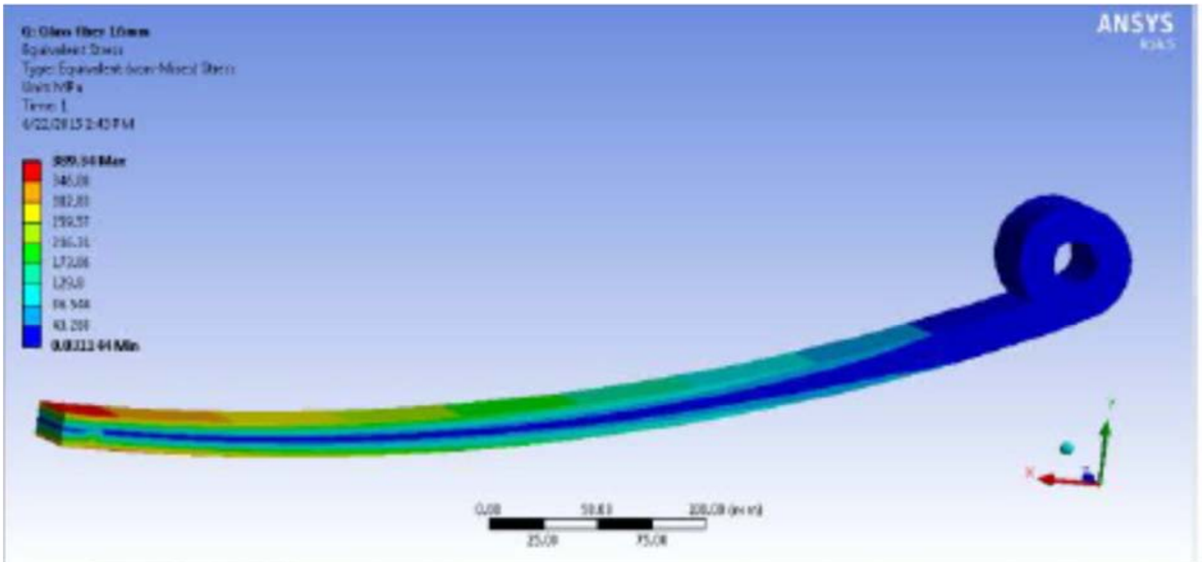


***Figure 7.*** *Stress distribution for Glass/Epoxy composite leaf Spring.*

# 8. Results & Discussion

Experimental results from testing the leaf springs under static loading containing the stresses and deflection are listed in Table 3. These results are also compared with FEA in Table 3. Testing has been done for unidirectional E-Glass/Epoxy mono composite leaf spring only. Since the composite leaf spring is able to withstand the static load, it is concluded that there is no objection from strength point of view also, in the process of replacing the conventional leaf spring by composite leaf spring. Since, the composite spring is designed for the same stiffness as that of steel leaf spring, both the springs are considered to be almost equal in vehicle stability. The major disadvantage of composite leaf spring is chipping resistance. The matrix material is likely to chip off when it is subjected to poor road conditions (that is, if some stone hit the composite leaf spring, it may produce chipping) which may break some fibers in the lower portion of the spring. This may result in the loss of capability to share flexural stiffness. But this depends on the condition of the road. In normal road condition, this type of problem will not be there. Composite leaf springs made of polymer matrix composites have high strength retention on ageing at severe environments.

The steel leaf spring was replaced with a composite one. The objective was to obtain a spring with minimum weight which is capable of carrying given static external forces by constraints limiting stresses (Tsai-Wu criterion) and displacements. The weight of the leaf spring is reduced considerably about 85% by replacing steel leaf spring with composite leaf spring. Thus, the objective of the unsprung mass is achieved to a larger extent. The stresses in the composite leaf spring are much lower than that of the steel spring.

***Table 3.*** *Comparison results of load, deflections and bending stresses.*

| Material | Static load (N) | Max. Deflection (mm) | | Max. Bending Stress (MPa) | | Wt. (Kg) |
|---|---|---|---|---|---|---|
| | | FEA | Expt | FEA | Expt | |
| Steel | 4000 | 92 | 105.9 | 507 | 503.7 | 24 |
| Composite | 4190 | 94 | 103.4 | 456 | 470.1 | 3.56 |

***Table 4.*** *Natural frequencies of composite leaf spring.*

| Modes | Frequency (Hz) |
|---|---|
| 1 | 31 |
| 2 | 129 |
| 3 | 180 |
| 4 | 298.4 |
| 5 | 360.9 |

Harmonic analysis has been done on composite leaf spring to find the modal frequency. The first five natural frequencies are listed in the Table 4. The natural frequency of composite leaf spring is higher than that of the steel leaf spring and is far enough from the road frequency to avoid resonance.

# 9. Conclusion

The development of a composite mono leaf spring having constant cross-sectional area, where the stress level at any station in the leaf spring is considered constant due to the parabolic type of the thickness of the spring & has proved to be very effective. The study demonstrates that composites can be used for leaf springs for light weight vehicles and meet the requirements, together with substantial weight savings. The 3-D modeling of both the steel and composite leaf spring is done and analyzed using ANSYS. A comparative study has been made between composite and steel leaf spring with respect to weight and strength.

The experimental results were compared with FEA and the results show good agreement with test results. From the results, it is observed that the composite leaf spring is lighter and more economical than the conventional steel leaf spring with similar design specifications. Composite mono-leaf spring reduces the weight by 85% for E-glass/Epoxy over steel (conventional) leaf spring.

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