DESIGN DEVELOPMENT & ANALYSIS OF COMPOSITE MONO LEAF SPRING

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ABSTRACT

Leaf spring is important element of suspension system. Ride comfort and load carrying capacity of vehicle mainly depend upon the leaf spring. It has to withstand numerous load cycles without fatigue failure so it is needed to assess the fatigue life of leaf spring.

In the present scenario, weight reduction has been the main focus of the automobile manufacturers .The suspension leaf spring is one of the most potential items for weight reduction in automobiles as it contributes to 10-20% of the unsprung mass. The introduction of composite materials made it possible to reduce the weight of the leaf spring without any reduction in load carrying capacity and stiffness. Stress, stiffness and fatigue life are the performance measures of the leaf spring.

In the present work, static and fatigue analysis of composite mono leaf spring made up of E-glass/epoxy material. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle are taken and are verified by design calculations. Static Stress, stiffness results obtained by analytical method (SAE Manual),numerical results (FEA) with experimental results. Also Fatigue analysis is carried out to assess the fatigue using numerical software ANSYS V14.5 and results are validated using experimental fatigue test. Weight reduction up to 66% is achieved for an E-glass composite in comparison with steel leaf spring fatigue life has been increased up to 66 Lac cycles.

Keywords: Composite Mono leaf spring, E-glass/Epoxy, Static analysis and fatigue life, Ride Comfort.

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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 unstrung weight. 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 counter parts.

Fatigue failure is the predominant mode of in-service failure of many automobile components. This is due to the fact that the automobile components are subjected to variety of fatigue loads like shocks caused due to road irregularities traced by the road wheels, the sudden loads due to the wheel traveling over the bumps etc. The leaf springs are more affected due to fatigue loads, as they are a part of the unstrung mass of the automobile.

The fatigue behavior of Glass Fiber Reinforced Plastic (GFRP) epoxy composite materials has been studied in the past. Theoretical equation for predicting fatigue life is formulated using fatigue modulus and its degrading rate. This relation is simplified by strain failure criterion for practical application. These studies are limited to mono-leaf springs only.

In the present paper, a steel spring used in passenger cars is replaced with a composite leaf spring made of glass/epoxy composites. The 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.

Design Development of Composite Leaf Spring

For design of any spring first it is required to finalize all the parameters. Here attempt to use a composite material for new spring so it is very important to find which parameters is mainly affect the performance of leaf spring.

Design of Experiment (Hence onward as DOE) is powerful technique used to exploring new process, gaining increased knowledge of existing process & optimizing these processes for achieving world class performance. Also DOE is achieving improvements in product quality and process efficiency.

DOE is formulated for the CFR(critical function requirement) as stress for the input variables are spring thickness, width & length.

Here we are considered four types of spring model at various dimensions and different loading conditions.

Run	Spring Thickness (mm)	Spring Width (mm)	Applied Force (N)	Von Mises Stress (Mpa)	DOE Transfer Function (von Mises Stress) (Mpa)
1	20	50	3000	165	165
2	20	30	1000	55	55
3	10	50	1000	170	170
4	10	30	3000	274	274

DOE Result Summary

For selection of material, only high and low levels are considered. So for two levels and three input factors, L4 array was selected. As per the L4 array, four experiments with following levels have been done.

Table: I Insert parameters for DOE

Based on DOE observation, following dimension were considered to manufacture actual spring & Static Analysis also performed for same dimension

Table: II Final Parameter from DOE

Spring thickness (mm)	Spring Width (mm)	Force (N)
10	50	1000

Finite Element Analysis.

CAD Modeling of any project is one of the most time consuming process. One cannot shoot directly from the form sketches to Finite Element Model. CAD(Geometry) Modeling is the base of any project. Finite Element software will consider shapes, whatever is made in CAD model. CAD modeling of the mono Leaf Spring structure is performed by using ANSYS Design Modeler software as per mention dimension in below table. The Geometry of leaf spring used for analysis is shown in fig.no 1 below.

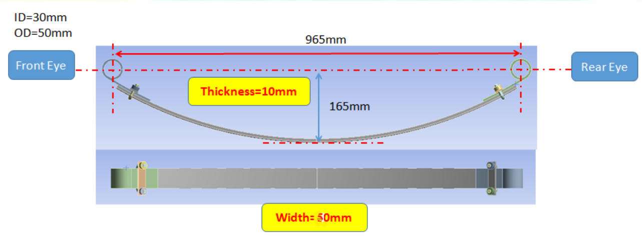

Fig.1: 3 D Model of Leaf Spring

Specification of Leaf Spring

Table: III Leaf spring specification

Parameters	Value
Total length of the spring (Eye to Eye)	965mm
Free camber (At no load condition)	165mm
Thickness of leaf	10mm
Width of leaf spring	50mm
Maximum load given on spring	1000N

Table: IV Mechanical properties of E glass/Epoxy material

Material properties	Value
Tensile modulus along X - direction (Ex)	34000
Tensile modulus along Y - direction (EY)	6530
Tensile modulus along Z - direction (EZ)	6530
Tensile strength of material, Mpa	900
Compressive strength of material, Mpa	450
Shear modulus along XY- direction (Gxy)	2433
Shear modulus along YZ- direction (Gyz)	1698
Shear modulus along XZ- direction (Gzx)	2433
Poisson ratio along XY- direction (N Uxy)	0.217
Poisson ratio along XY- direction (N Uyz)	0.366

Static Analysis of Composite Mono Leaf Spring

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. A static structural load can be performed using the ANSYS solver. The types of loading that can be applied in a static analysis include:

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain)

For the above given specification of the leaf spring, the static analysis is performed using ANSYS 14.5 to find the maximum safe stress and the corresponding pay load. After geometric modeling of the leaf spring with given specifications in ANSYS Design Modeller then it is subjected to analysis. The Analysis involves the following discretization called meshing, boundary conditions and loading.

Meshing

Meshing involves division of the entire of model into small pieces called elements. This is done by meshing. It is convenient to select the free mesh because the leaf spring has sharp curves, so that shape of the object will not alter. To mesh the leaf spring the element type must be decided first. Here, the element type is solid186 for leaf spring & solid187 for steel plate, U clamp & bolts.

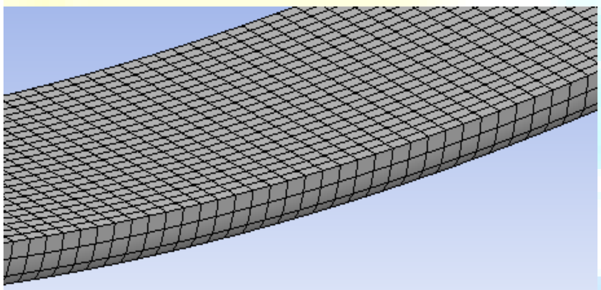

Fig.2: Meshing Model of E Glass/Epoxy Leaf Spring

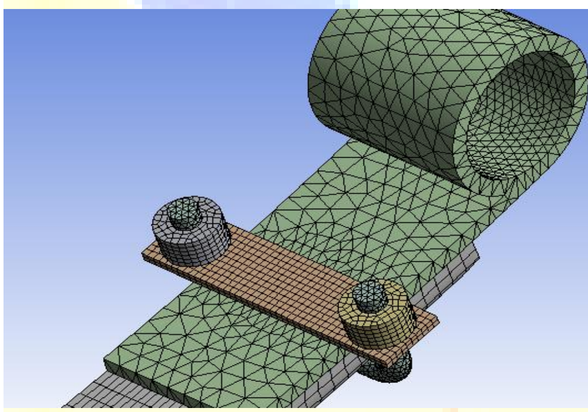

Fig.3: Meshing Model of E Glass/Epoxy Leaf Spring with steel Eye

D.O.F. constrained	Front eye	Rear eye
Translation constrained	X, Y and Z direction	Y and Z direction
Rotation constrained	X and Z direction	X and Z direction
Allowing	Free Y rotation	Free X translation and Y

Boundary Conditions

The leaf spring is mounted on the axle of the automobile; the frame of the vehicle is connected to the ends of the leaf spring. The ends of the leaf spring are formed in the shape of an eye. The front eye of the leaf spring is coupled directly with a pin to the frame so that the eye can rotate freely about the pin but no translation is occurred. The rear eye of the spring is connected to the shackle which is a flexible link; the other end of the shackle is connected to the frame of the vehicle. The rear eyes of the leaf spring have the flexibility to slide along the X-direction when load applied on the spring and also it can rotate about the pin. The link oscillates during load applied and removed. Therefore the nodes of rear eye of the leaf spring are constrained in all translational degrees of freedom, and constrained the two rotational degrees of freedom. So the front eye is constrained as UX, UY, UZ, ROTX, ROTY and the nodes of the rear eye are constrained as UY, UZ, ROTX, ROTY. Figure below shows the boundary conditions of the leaf spring.

Table :V Boundary Conditions of Composite Leaf spring

The load is distributed equally by all the nodes associated with the centre bolt. The load is applied along 'Fy' direction as shown in Figure. To apply load, it is necessary to select the centre edge and consequently the nodes associated with it. It is necessary to observe the number of nodes associated with the edge, because the applied load need to divide with the number of nodes associated with the circumference of the Centre edge

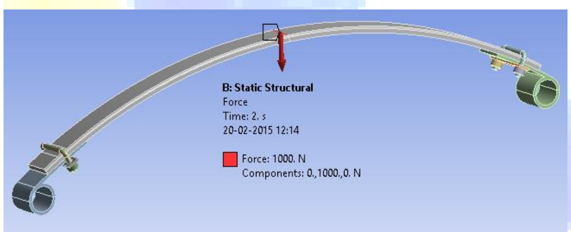

Fig.4: 1000 N Force Applied On Spring

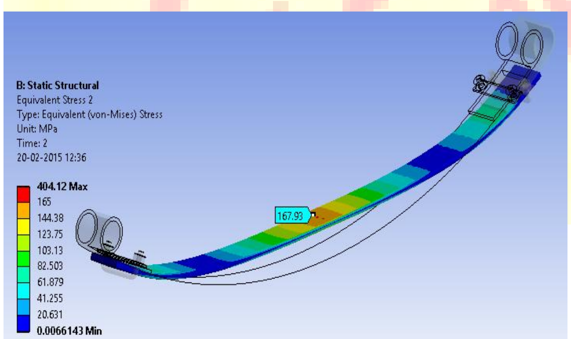

Fig.5: Stress plot

Fatigue Analysis of Leaf Spring:

Stress Life based on empirical S-N curves is considered here to calculate fatigue life of leaf spring. Constant amplitude with fully reverse loading were considered with Goodman theory for the mean stress.

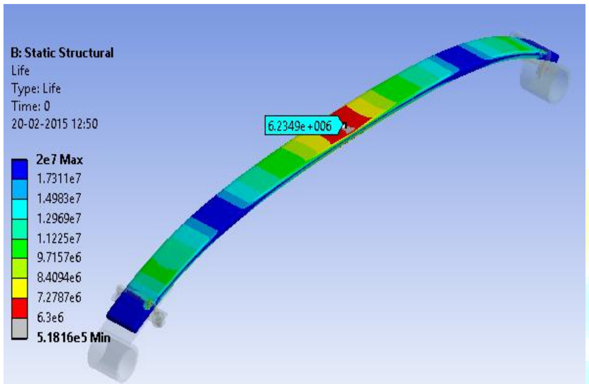

Fig.6: Life plot of Composite Leaf spring.

Material used for reinforcement is E glass fibrerovings,which weight is 360 g per sq.m.. The resin selected is liquid diglycidyle ether of Bisphenol A type (Araldite LY556) which has a density of 1.15-1.20 g/cm^3. It is easy to process and has good fibre impregnation properties and good mechanical and thermal properties hand layup method is quite suitable for manufacturing the composite leaf spring. . Hand layup method is adopted for fabrication due to its advantages over the others. Tooling cost is low, No skilled worker is required, large items can fabricate, easy method than etc.

Fabrication of Composite Leaf spring.

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One problem was face while manufacturing the spring the E Glass fiber sheet is difficult to bending & sticking the sheet one above another. So we were fabricating the spring without eye. And additional steel eye were attaching to the composite leaf spring with the help of U-clamp. After 24 hrs separate the steel leaf spring from composite leaf spring. By this process finally we get the Composite leaf spring without eye. Here we have bolted steel eye to both end of the composite leaf spring with the help of U clamp.

Fig.7: Final output of composite Leaf spring with steel eye.

Experimental setup

The following sections of this chapter will elaborate the procedures for conducting the experiments of steel and composite Leaf spring analysis by using Universal Testing machine and Fatigue testing machine.

After the fabrication, the composite mono leaf springwas tested with the help of an electro-hydraulic leaf springtest rig. Steel leaf spring weighs 4.5 kg whereascomposite leaf spring weighs only 1.5 kg. For a lightpassenger vehicle with a camber height of 165 mm, thestatic load to flatten the leaf spring is theoreticallyestimated to be 3250 N. Therefore a static vertical force of2000N is applied to determine the load-deflection curves as well as load- stress curve.

A load is applied further from the static load tomaximum load with the help of the electro-hydraulic testrig, up to 3250 N (165 mm deflection), which is alreadyobtained in static analysis. The test rig is set to operate fora deflection of 50 mm. This is the amplitude of loadingcycle, which is very high. The frequency of load cycle isfixed at 1 Hz, as only 60 strokes/min is available in thetest rig used. This leads to high amplitude low frequencyfatigue test.

The maximum and minimum stress values obtained atthe first cycle of the composite leaf spring are 178MPaand 115MPa respectively at load 1000 N. As the cycles go on increasing,the stress settling is happening only after 25000 cycles.These maximum and minimum operating stress values are245MPa and 148MPa respectively. Because of very lowstress level, the fatigue life of the composite leaf spring isvery high under simulated conditions

Result and Discussion

By using experimental tabulated data graphs are plotted for Load - Von-Mises stress for Steel and Composite leaf spring. This will help to find out which material has better stiffness and better loading capacity

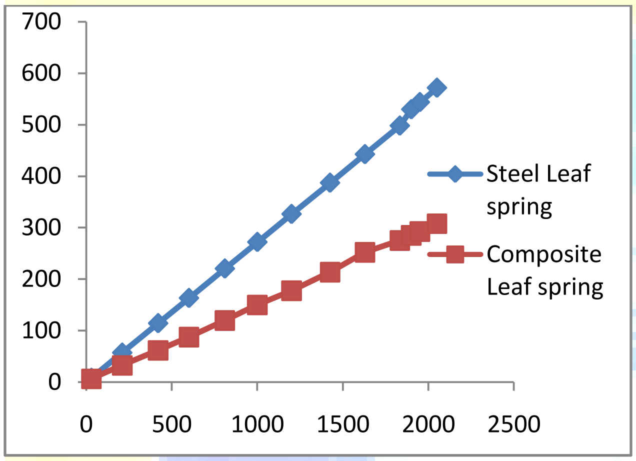

Fig.8: Load - Von-Mises stress for Steel and Composite leaf spring.

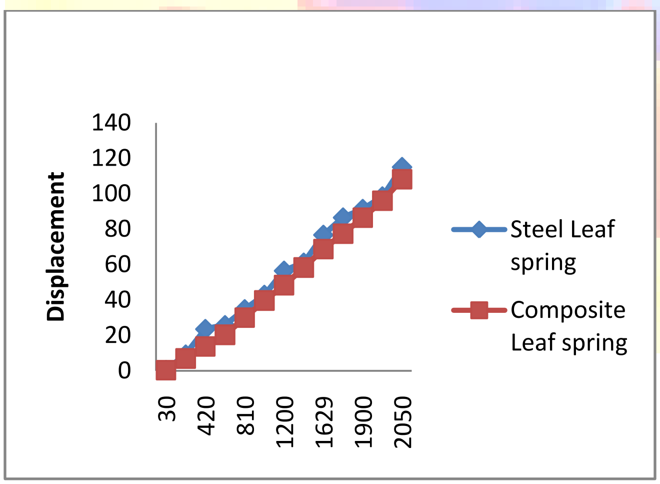

Fig.9: Load – Displacement for Steel and Composite leaf spring.

Fatigue test is carried out on Fatigue testing machine. Following are the observed.

Table.VI: Fatigue Test cycle

Leaf Spring	Required Fatigue Cycle	Test Load (min)	test Load (Max)	Frequency (Hz)	Fatigue test Result (Cycle)
1	100000	1000	1500	1	125319

Table.VII: results from data acquisition system

<table>
<tr><th>Main Leaf Spring</th><th>Displacement (mm)</th><th>Stress (Mpa)</th><th>Position From centre (mm)</th><th>No of cycle</th><th>Load (N)</th></tr>
<tr><td>Front</td><td rowspan="4">49.65</td><td>176</td><td>115</td><td rowspan="4">20000</td><td rowspan="4">1000</td></tr>
<tr><td>Front</td><td>115</td><td>430</td></tr>
<tr><td>Rear</td><td>178</td><td>118</td></tr>
<tr><td>Rear</td><td>118</td><td>435</td></tr>
<tr><td>Front</td><td rowspan="4">62.31</td><td>242</td><td>115</td><td rowspan="4">125319</td><td rowspan="4">1500</td></tr>
<tr><td>Front</td><td>148</td><td>430</td></tr>
<tr><td>Rear</td><td>245</td><td>118</td></tr>
<tr><td>Rear</td><td>125</td><td>435</td></tr>
</table>

The fatigue tests of leaf springs are made byblock cycle loading of 100,000 cycles for the load 1000N and 1500N with frequency 1Hz. This result is very close toresults of the FEA studies

Comparison of Steel leaf & Composite leaf spring results.

To get experimental results, experimental readings are taken. All the experimental data was tabulated as per following.

Table.VIII: Comparison of Steel Leaf & composite leaf spring results.

Parameter	Steel Spring	Composite Leaf Spring	
		Experimental	FEA
Force(N)	1000	1000	1000
Weight(Kg)	4.91	1.5	1.5
Stress(MPa)	272.00	150.00	167.93
Deflection(mm)	42.80	39.62	46.43
Stiffness(N/mm)	23.37	25.23	20.96

1. From above table it is observed that the static deflection of composite leaf spring from experimental having 17 % variation with FEA results.
2. Also bending stress of composite leaf spring from experimental has 12 % variation with FEA results.

   This shows very good correlation. Hence we may predict the fatigue life of leaf spring by FEA approach.

3. Composite Leaf spring will sustain until 6.2349e6 repeated cycle which come under high cycle fatigue.

Conclusions

Design and experimental fatigue analysis of compositemono leaf spring using glass fibre reinforced polymer arecarried out using life data analysis. Compared to steelspring, the composite leaf spring is found to have 67.35 %lesser stress, 64.95 % higher stiffness and 126.98 % highernatural frequency than that of existing steel leaf spring.The conventional mono leaf spring weigh is about 4.5 kgwhereas the E-glass/Epoxy multi leaf spring weighs only 1.5 kg. Thus the weight reduction of 66.65 % is achieved.Besides the reduction of weight, the fatigue life ofcomposite leaf spring is predicted to be higher than that ofsteel leaf spring. Life data analysis is found to be a tool topredict the fatigue life of composite multi leaf spring. It isfound that the life of composite leaf spring is much higherthan that of steel leaf spring

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